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RADC-TR-74-266
Technical Report
November 1974

EVALUATION OF ENVIRONMENTAL PROFILES FOR RELIABILITY DEMONSTRATION

Grunman Aerospace Corporation

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Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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EVALUATION OF ENVIRONMENTAL PROFILES FOR RELIABILITY DEMONSTRATION

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This report describes the effort during the first 12 months of an 18-month study to determine the adequacy of the environmental profiles of MIL-STD-781, "Reliability Tests: Exponential Distribution," and provide recommendations for their improvement. The environmental and failure history of a sample of 95 avionic WRA's served as the vehicle for this evaluation. Environmental data during demonstration testing and actual field exposure for each WRA was collected, analyzed, and compared. Test failure history and field failure

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20. ABSTRACT (continued)

experience have been reviewed and reliability measures for each have been determined. New reliability predictions in accordance with the coordination copy of MIL-HDBK-217B have been performed. Preliminary comparisons of lab-field reliability differences with environmental differences indicate that temperature rate of change, vibration method, and the length of exposure to vibration during testing are significant factors. It was also found that groundrules and failure scoring criteria have a strong impact on reliability differences.

PREFACE

This Interim Technical Report was prepared by Grunman Aerospace Corporation, Reliability and Maintainability Section, Bethpage, New York, under Contract F30602-73-C-0317, Job Order 55190262, for Rome Air Development Center, Griffiss Air Force Base, New York. Mr. Lester J. Gubbins (RBRS) was the RADC Project Engineer.

The effort described was accomplished during June 1973 through May 1974.

Technical consultation on environmental analyses was provided by Mr. David L. Earls (AFFDL/FEE) of the Air Force Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio.

Additional Grunman study team members were: Mr. Lawrence Kutin, Mr. Joseph Osche, Miss Linda Kuttner, Mr. Joseph Popolo, Mr. John Campbell, Mr. Lawrence Flanagan, and Mr. Harvey Hott.

This technical report has been reviewed and is approved.

APPROVED: Lester J. Gubbins

LESTER J. GUBBINS
Project Engineer

APPROVED: Joseph J. Naresky

JOSEPH J. NARESKY, Chief
Reliability & Compatibility Div.

FOR THE COMMANDER: James G. McGinnis

JAMES G. McGINNIS, Lt Col,USAF
Deputy Chief, Plans Office

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SECTION I

INTRODUCTION

1.1 Background

Grumman experience indicates that the reliability of avionic equipment in the field is almost always lower than that demonstrated in the laboratory. A relative difference between 3:1 and 5:1 is common and in some cases it even extends to orders of magnitude. The incompatibility between lab and field MTBF significantly impacts life cycle costs (maintenance planning and sparing of resources) and also impedes the early achievement of reliability goals. Factors which may significantly contribute to reliability differences include:

- Environment

  Data and experience seem to indicate that differences between lab tests and field environmental exposure is one of the more significant reasons for reliability incompatibility. Increased environmental stress levels on hardware due to modern high speed, high performance aircraft are responsible for many field failures. A study performed by Grumman (ref. 1) clearly indicates that almost 50% of field failures are environmentally related.

- Level of Maintenance Skills

  The skill level of personnel engaged in the maintenance and repair of avionic equipment can affect reliability. Inadequate or incorrect diagnosis would result in erroneous failure entries. Unskilled repair actions could result in additional failures induced during the repair process again resulting in erroneous conclusions. In addition, poor equipment handling practices due to lack of proper maintenance stands, etc., or lack of personnel motivation could result in induced failures.

- Functional Test Equipment Incompatibility

  During the earlier stages of aircraft deployment, test equipment and hardware may not be completely compatible and this incompatibility could result in erroneous failure diagnosis during troubleshooting.

Incorrect failure data would then be entered into the data recording system.

- Inconsistencies In Prediction Methods

  Since the equipment manufacturer must prove via a prediction that his parts, etc., have the reliability required to permit the achievement of a specified reliability value, it is important that this prediction be realistic and based on best available data. In addition, it is also important that a uniform prediction policy be maintained for all avionic equipment. Current techniques utilize data from a wide variety of sources, which often result in equipment whose measured values of MTBF do not approach the original requirement.

- Maturity of Systems Selected for Reliability Demonstration Tests

  Quite often, in order to meet contractual schedule commitments, production equipment is delivered before the reliability demonstration test is complete. Many problems may be detected during the demonstration test for which a change will not be incorporated into the production hardware until some later date. Therefore, until some point in time, the reliability of field hardware may be lower than the demonstrated value.

- Diversified Black Box Aircraft Location Vs. Single Subsystem Lab Environmental Conditions

  Almost without exception, laboratory demonstration tests conducted on a subsystem composed of several WRA's, are performed in one test facility and at one level of environmental stress. In the aircraft these same units are generally located in different locations and exposed to different environmental conditions. Even if all items are designated to be the same MIL-E-5400 "class", which indicates thermal and altitude tests only, other environmental conditions (notably vibration) may vary considerably.

- Laboratory and Field Ground Rules for Establishing an MTBF

  Ground rules for failure definition and time measurement must be consistent to assure that field and lab reliability comparisons are

valid. It seems obvious that a large disparity between these parameters when used in defining MTBF and scoring failures will result in a significant difference in reliability.

It is apparent that reliability demonstration tests do not adequately reflect field usage. Therefore this study focuses on this aspect and primarily on the effect of environment. This appears to be the most viable area of investigation at this time because:

- Our experience shows that the laboratory does not duplicate field environment.
- Profiles have remained essentially unchanged for many years.

To a lesser extent, but because they are so intimately tied to reliability measurement, we will also examine the effect of ground rules and predictions.

1.2 Objectives

The principal objectives of this study are:

- Determine the adequacy of the environmental profiles of MIL-STD-781 in simulating field stresses.
- Where inadequacies exist, provide recommended new test profiles for inclusion in MIL-STD-781.

Secondary objectives include:

- Determine the adequacy and provide recommendations for improving demonstration test ground rules and scoring criteria.
- Identify changes needed in reliability prediction methods to produce better correlation with demonstration and field results.

1.3 Approach

To satisfy these objectives the study includes the following general areas of investigation:

- A selection of Weapons Replaceable Assemblies (WRA's) in accordance with a set of criteria developed to assure a cross section of function, location, cooling and mounting provisions, etc.

(Ninety-five distinct WRA's were selected.) Note that "WRA" is a generic term used to describe any replaceable package of an avionic equipment or system as installed in an aircraft weapon system. The equivalent Air Force term is Line Replaceable Unit (LRU).

- A determination and comparison of actual use and demonstration test environments, levels, and duration of exposure.
- A review and analysis of demonstration test results and field failure experience to determine respective MTBF's.
- An analysis to relate MTBF differences to environmental differences to identify and quantify areas of influence.
- A development of new environmental profiles, their range of validity, and methods for modification in the future.
- A reprediction of reliability to a common source document and with a common set of ground rules. (The coordination copy of MIL-STD-217B, dated Jul 73, was used for this effort.)
- An analysis to relate differences between predicted and field MTBF's to differences in equipment characteristics and environmental differences for the purpose of identifying areas of improvement in prediction methods.

1.4 Report Scope

This interim report covers the work performed during the first 12 months of a contemplated 18 month study. A sample of 95 WRA's has been selected and the physical and design characteristics of each have been determined. Environmental data relating to laboratory testing and actual field exposure for each WRA has been collected, analyzed, and compared. WRA test results and field failure experience has been reviewed and reliability measures for these conditions have been determined. New reliability predictions for each selected WRA have been performed. Some preliminary comparisons of lab-field reliability differences to environmental differences have been made and several relationships have been observed.

The effort during the balance of the study will concentrate on the following areas:

- Refining field reliability values to consider certain types of false alarms and to more precisely eliminate non-relevant failures by an analysis of failure modes.
- Quantifying the relationship between reliability differences and environmental differences.
- Developing new environmental profiles.
- Studying the relationship between predicted and field reliability differences for various categories of equipment characteristics and environments.

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SECTION II
EQUIPMENT DESCRIPTION

2.1 Selection Criteria

In determining which items to select for use in this study, many equipment attributes were evaluated. The basic rationale for final selection included two primary considerations:

- To what extent was the criterion affected by environment?
- To what extent was reliability influenced by the criterion?

Utilizing the above rationale, the following attributes were applied in selecting the study equipments:

- Laboratory Demonstration - In order to perform any evaluation it was implicit in the basic study objective that each selected equipment must have been subjected to a reliability demonstration test. The equipments chosen have all been subjected to such tests, predominantly levels E & F of MIL-STD-781 (ref. 2). Certain equipments were purposely selected because they had not been exposed to a MIL-STD-781 profile, instead they were tested to environments representing typical mission profiles.

- Contemporary Design - The primary driver used when considering vintage of equipment was state-of-the-art technology. Since the study output was aimed at recommending profiles for future tests, it was important that analysis be performed on equipment representing current technology. Further, if the equipment evaluated was too old, maximum reliability growth would have been achieved via ECP action, and any comparison between lab and field would contain a built-in bias. Of course, equipment had to be mature enough to be deployed so that data would be available. This contradiction was mitigated somewhat by selecting equipment with a large complement of microcircuitry (I/C's, etc.) as well as other unique and current design features. In addition, equipment was also selected which included a mix of parts/quality levels.

- Weapon System Diversity - Since the environmental exposure an equipment experiences is somewhat dependent upon the characteristics of the aircraft it is installed in and its associated mission profile, equipments have been selected from a variety of aircraft weapon systems to assure a cross section of environmental exposure. The aircraft represented in this selection include:

  - Turbojet and turboprop propulsion
  - Subsonic and supersonic speeds
  - Land and carrier basing
  - Attack, fighter, and surveillance missions

- Location In Aircraft - To provide diversity of environmental intensity and to establish a base for MIL-STD-781 test comparisons (since lab tests are primarily conducted on subsystems under one set of environments while actual aircraft location may include many environments for the same subsystem), equipment was selected from the nose, fuselage body, cockpit, tail, etc.
- Cooling Method and Mounting - In order to establish a base for comparison of thermal cycling effects, equipment was selected from classes 1A, 1X, 2, 2A and 2X as defined by MIL-E-5400 (ref.3) and encompassed natural convection, liquid, forced air, and fan cooling methods. In a similar manner, both hard-mounted and isolator-mounted equipments were selected to enable an assessment of different field performance (since MIL-STD-781 tests call for hardmounting of all test hardware).
- Usage - All equipment selected and used in the aircraft types defined will be produced in quantity. Further, all common equipment functions are represented in the selected hardware, i.e., radar, communications, navigation, computer functions, displays, A-D converters, high-power transmission, sensors, etc.

- Field Reliability - Availability of data and thorough knowledge of environmental "use" parameters also dictated the choice of hardware. Since the equipments selected are presently included in the Navy inventory, field data is available through the 3M system and can readily be supplemented by available preflight and flight test data. Further, environmental profiles have been determined for each of the aircraft selected.

2.2 Equipment Descriptions

In order to provide some insight into the equipments selected for the study, a brief description of each of the WRA's is presented. After reviewing each of the equipments it was decided to group them into categories based on the generic function of each unit, i.e., data processing, RF transmission, etc.

RF R/T - WRA's which either transmit or receive RF signals are included in this grouping.

WRA No. 1 is an RF receiver and is located in the upper left-hand shelf of the aft equipment bay structure. Two bolts in the front and two spring loaded alignment pins in the rear provide a rigid mounting for the assembly. All fuses, connectors and an elapsed-time meter are on the front panel. During normal operation, cooling air is scooped into the rear air inlet and fed out the front exhaust to maintain a proper operating temperature.

WRA No. 2 is an RF transmitter consisting of 19 oil-cooled ceramic tetrodes operated as a class A distribution amplifier. They are divided into driver, intermediate and final stages which amplify the output of the control to the proper level for transmission. There are four basic modes of operation and, depending upon the mode selected, various sub-modes and routines.

WRA No. 3 is an RF receiver. The unit is functionally subdivided into three parts: transmitting, search receiving, and terrain clearance receiving. The unit is located in the nose of the fuselage and is accessible by raising the fiber glass radome. It is ambient cooled and hard mounted.

WRA No. 4 is an RF receiver and is housed in the upper right portion of the aft equipment bay structure. Two bolts in the front and two spring-loaded alignment pins on the rear provide a rigid mounting for the assembly. All fuses, connectors, and an elapsed time meter are on the front panel. During normal operation, cooling air is scooped into the rear air inlet and is fed out the front exhaust to maintain a proper operating temperature.

WRA No. 5 is an RF receiver and is located in the left wing fillet. The receiver has a metal case with three electrical and six coaxial connectors. An elapsed-time indicator is visible on the front of the receiver unit. It is hard mounted and ambient cooled.

WRA No. 6 is an RF receiver and is housed in the forward portion of the receiver compartment. Four bolts in the front and two spring-loaded alignment pins in the rear provide a rigid mounting for the assembly. All fuses, connectors, and an elapsed-time meter are on the front panel. During normal operation, cooling air is scooped into the rear air inlet and is fed out the front exhaust to maintain a proper operating temperature.

WRA No. 7 is an RF transmitter located in the fuselage nose, which provides continuously adjustable high-energy pulses of selectable width and repetition rate. The unit contains 13 removable assemblies and three harness assemblies with integral filters, connectors, and relay circuitry. It consists of two separate cast aluminum rectangular housings secured together to provide a single unit, and four shock mounts provide for installation in the aircraft. Forced air is required for proper cooling. The forced air is applied to an intake opening in the bottom of the housing, circulated past four heat-exchanger plates, and exhausted through vents on the top of the housing. Nitrogen or dry air is required for proper pressurization.

WRA No. 8 is an RF transmitter consisting of 19 oil-cooled ceramic tetrodes operated as a class A distribution amplifier. They are divided into driver, intermediate and final stages which amplify the output of the control to the proper level for transmission. There are four basic modes of operation and depending upon the mode selected, various sub-modes and routines.

WRA No. 9 is an RF receiver-transmitter, located in an equipment bay, that is capable of receiving and transmitting voice and data. The unit is housed in a 1/2-ATR case with the right side cover removable for module accessibility. All modules interconnect through a printed circuit sideboard which also contains a terminal field for soft wire interconnection to the I/O connector. The receiver-transmitter contains mechanical filters, crystal filters, and wide dynamic range front-end circuits that provide rejection of strong adjacent channel signals.

WRA No. 10 is an RF receiver and is housed in the forward portion of the receiver compartment. Four bolts in the front and two spring-loaded alignment pins in the rear provide a rigid mounting for the assembly. All fuses, connectors, and an elapsed time meter are on the front panel. During normal operation, cooling air is scooped into the rear air inlet and is fed out the front exhaust to maintain a proper operating temperature.

Signal Processing - Items which deal directly with electronic signals, i.e., processing, modulation, amplification, attenuation or filtering, comprise this group.

WRA's Nos. 11 and 12 are signal processing units that decode firing signals. Each unit contains two printed circuit cards hard wired to each other and an interface connector. Most of these units are hard mounted to a weapons rail.

WRA No. 13 is a signal data converter which provides timing pulses. In addition, the unit processes the RF returns for presentation by various displays. It is housed in an aluminum case with four mounting brackets and a carrying handle. Six electrical connectors and an elapsed-time meter are on a connector panel at one end of the unit. The unit is located in the nose.

WRA No. 14 is a signal processor which generates pulsed outputs in response to an input. The unit consists of a single equipment cabinet, hard mounted in a frame enclosure in the fuselage equipment bay. Cooling is provided by controlled forced air from vapor cycle system. Various connectors, controls and an elapsed time meter are located on the cabinet's front panel.

WRA No. 15 combines RF inputs from various units into one signal representing the sum of the inputs, and applies this combined signal for further processing. The unit is hard mounted on the fuselage top deck and is ambient cooled.

WRA No. 16 is a network which suppresses transients in the 115 vac and 28 vdc aircraft power lines. The network is mounted in the nose of the aircraft.

WRA No. 17 is a comparator-converter which receives and processes video signals. It is housed in the lower right-hand corner of the aft equipment bay structure. The assembly is secured in place by two spring-loaded alignment pins at the rear and by two bolts in the front which attach to the aft equipment bay structure. An elapsed time meter, cable connector, and fuses are mounted on the front panel of the assembly. During normal operation, cooling air is scooped into the rear air inlet and is fed out the front exhaust to maintain a proper operating temperature.

WRA No. 18 is a unit that splits a combined signal sample into six signals of equal magnitude and applies these signals to various receivers. The unit is mounted in the tail fin area of the aircraft and is ambient cooled.

WRA No. 19 is a control unit used to provide an RF drive corresponding to the assigned frequency of either of two transmitters. An RF sample of the carrier frequency produced is sent to other subsystems for sample display. A BIT feature is included to self test the unit. The unit is cooled by liquid circulated within a heat exchanger. The exchanger is cooled by external air.

WRA No. 20 is a signal processor containing receiver, gate and logic channels, a BITE network and a power supply. The unit is hard mounted in the right forward equipment bay and is cooled by an internal fan.

WRA No. 21 is a 3-pole bandpass filter that is tunable in four bands. The filter provides front-end protection to the receiver-transmitter from strong off-frequency signals and also provides selectivity for the receiver-transmitter. It is housed in a 1/4-ATR (short) case and contains four plug-in printed circuit card assemblies. The unit is completely solid state and no special cooling is required. It is located in an equipment bay.

WRA No. 22 is a broad band filter assembly and is located within the aircraft wing. It is housed in a metal case with two electrical connectors and six coaxial connectors. It is hard mounted and ambient cooled.

Interfaces - Devices which act as interfaces, junction boxes, couplers and converters make up this category.

WRA No. 23 is a display/converter which functions as the interface between a computer and indicator and display units. It is forced air cooled and isolator mounted. It is located in the fuselage.

WRA No. 24 is an analog-digital converter and serves as the interface between a computer and analog data devices. The unit contains 39 plug-in printed circuit cards, which are held in place by tie-down bars. To enable cooling of electronic components, large areas of copper extend outward from the plug-in printed circuit cards. Heat transfers from the components to the copper pad and ultimately to the chassis walls. The front panel of the unit contains controls, indicators, and seven operational connectors. It is located in the fuselage behind the cockpit.

WRA No. 25 is an interface box which provides for common distribution and preprocessing of signals for various displays and controls. Lamp-driver circuits provide for illumination of legend indicators on the BIT control, and dc outputs are provided for assemblies in the cockpit. This unit is located in the cockpit and is secured in place by two bolts which pass through a mounting structure at the front and two holes at the rear which mate with tapered locating pins.

WRA No. 26 is a converter which functions as the interface unit for control, data transmission, data storage, and navigation parameter display between a computer and navigation equipment. The unit is isolator mounted and receives supplemental cooling air. It is located in the fuselage equipment bay.

WRA No. 27 is a control interface unit and is part of a computer set. It provides the controls, displays and circuitry required to enter and transfer data, control computer operating modes, and control radar cursors. The unit consists of three removable subassemblies. Forced air cooling is supplied through a vertical air inlet manifold. It is located in the cockpit.

WRA No. 28 is an interface unit which provides an interface between a computer and the aircraft navigation system. The computer interface is located in the aft equipment bay structure. It is secured in place by two drilled mounting plates at the front, and two alignment pin sockets at the rear. Signal connectors, power connectors, fuses, and an elapsed time meter are located on the front panel, and a test connector is located at the rear. Cooling air is circulated through the assembly via four inlet ports at the rear and four exhaust ports at the front.

WRA No. 29 is an interface unit which provides the capability of communications between digital data equipment over a radio link. The unit converts binary information to a phase-encoded audio format suitable for hf or uhf radio transmission and vice versa. A card cage within the case supports up to 30 perpendicularly mounted plug-in circuit cards. Cooling of the data terminal is accomplished using forced-air cold-plate techniques. It is located in the equipment bay.

WRA No. 30 is an interface unit which provides computer data for aircraft radar operation. The equipment receives selected video and all required range and azimuth timing signals to digitally process the video into computer data. The unit is housed in a rectangular aluminum case that is locked in place by two latch sets. Cold plate heat exchangers are utilized with forced-air cooling to satisfy the cooling requirements. The unit is located in the aircraft nose.

WRA No. 31 is an interface box which provides distribution and preprocessing of signals for video displays and for audio signals. This unit is located in the aft cockpit and it is secured in place by two bolts which pass through a mounting structure at the front and two holes at the rear which mate with tapered locating pins. Except for the elapsed time meter at the front of the assembly, there are no controls or indicators. External connectors are located at the front top.

WRA No. 32 is a converter which acts in an interface capacity between a computer and data links. It is located in the fuselage equipment bay and requires forced cooling air.

WRA No. 33 is a high-speed, automatically tuned hf antenna coupler that transforms the complex impedance of the antennas to a value that is suitable as a load for a power amplifier. The unit is housed in a 3/4-ATR case and contains 12 removable modules. The modules are printed circuit cards and modularized assemblies. The WRA is forced-air ambient cooled by a blower and is located in an equipment bay.

WRA No. 34 is an interface unit which provides signal data interface control within a computer group between the processor, computer control, and tape recorder. It is forced air cooled and isolator mounted within the fuselage equipment bay.

WRA No. 35 is an interface unit which accepts synchro signals from various electromechanical sensors and supplies compatible synchro outputs to other requiring systems. The WRA consists of three modules and a self test assembly contained within a frame. The unit is hard mounted in the aft equipment bay and is ambient cooled.

WRA No. 36 is an antenna interface unit which generates the appropriate interlocks required for system and antenna protection. The unit is housed in a 1/4-ATR case and contains four plug-in printed circuit card assemblies. The unit is isolator mounted and requires no supplemental cooling air. It is mounted in the equipment bay.

Data Processing - This category includes items which perform computational (arithmetic) and similar functions.

WRA No. 37 is a general-purpose digital computer, which processes real-time control applications. In these applications, bombing and navigational computations are made based upon stored and computed flight data. Comprehensive self-test features are built into the computer to assist in fault isolation. The exterior structure provides cooling, interface connection, and electromagnetic shielding. The unit is mounted in the cockpit.

WRAs No. 38, 39, and 40 are computers which generate roll, pitch, and yaw control surface commands respectively. Each unit is housed in a structural box assembly and the two main structural members provide the mounting for all circuit board connectors. Electronic components within each computer are mounted on circuit boards accessible through the top cover. They are all located in the equipment bays.

WRAs No. 41, 42, and 43 are three types of arithmetic and control assemblies that act collectively as a central processor unit and perform five control functions: instruction, arithmetic, memory, program level and input/output. They are forced air cooled and isolator mounted and are located in the fuselage.

WRA No. 44 is a computer consisting of various generator and detector circuits, BITE circuits and a power supply. The unit is hard mounted within the wing and is cooled by an internal fan. Ten electrical connectors, one cooling air intake screen, an elapsed time indicator and an overheat indicator - reset button are on the unit's front panel.

WRA No. 45 is a computer which generates coded signals in response to specific inputs. It is housed in a cabinet which is hard mounted to a frame type enclosure in the fuselage equipment bay. Forced air cooling is provided by controlled air from a vapor cycle system. Various connectors, controls and an elapsed time meter are located on the front panel of the cabinet.

WRA No. 46 is a navigation computer that interfaces between various navigation subsystems and auxiliary equipment. It consists of an analog-to-digital-to-analog converter and a miniature general-purpose computer. The unit is located in an unpressurized equipment bay and is forced air cooled.

WRA No. 47 is a core memory assembly which consists of a destructive readout, coincident current, core stack assembly and a memory selector. The memory selectors contain the necessary circuits for addressing the memories and for providing access by two central processors on a time-sharing basis. The unit is forced air cooled and isolator mounted. It is located in an equipment bay.

WRA No. 48 is a processor which processes data inputs from other aircraft systems for display. Based on the mode selected and navigation submode

selected the processor sets the appropriate priority for each indicator and generates deflection signals necessary for display of required data. The unit is forced air cooled and isolator mounted and is located in an equipment bay.

WRA No. 49 is a computer containing a power supply and a memory which operates in various modes. The unit is housed in a single cabinet which is hard mounted to a frame enclosure located in the fuselage equipment bay. Cooling is provided by forced air from the aircraft's vapor cycle system. A temperature sensing switch is located on the top panel of the cabinet.

WRA No. 50 is a combined interface and processor unit which together form a stored program, parallel, binary computer whose purpose is to receive data inputs, process these inputs with programmed routines and provide capability for display and return of processed data. It is located in the aft equipment bay structure and is forced air cooled.

WRA No.51 is an air data computer which computes true air speed, impact pressure and altitude from static and total pressure supplied by the pitot static system. These computed quantities are supplied upon request to various components. The unit is fully automatic and is completely solid state. It consists of 16 printed circuit cards which plug into a mother board mounted to the chassis.

WRA No. 52 is a 4K coincident-current, random access-type memory whose function is to refresh the symbols for three independently operated indicators. It is located in the fuselage equipment bay and requires forced air cooling.

Indicators and Controls - Video display, control and personnel indication functions located in the aircrew compartment are included in this category.

WRA No. 53 is a flight control panel consisting of switches and circuitry which permit engagement of stability augmentation or autopilot flight modes. The unit consists of a flat, machined aluminum plate to which the connector bracket, switches and electroluminescent panel are attached. The case is an aluminum can which fastens to the panel with four screws.

WRA No. 54 is an indicator which provides alphanumeric and indicator light presentations. The unit is located in the cockpit at the operator

console, and is supported by two mounting pins at the rear and eight quarter-turn fasteners on the front panel. All indicators are located on the front panel and all connectors and elapsed time meter are located at the rear.

WRA No. 55 is an indicator which provides computer readouts and controls. To perform its various functions, this unit provides manual display mode control of computer data, display of system advisory flight and navigation data, and manual control of magnetic variation and display of magnetic variation data.

WRA No. 56 is an equipment which provides the operator with controls necessary to apply power to various assemblies and to select modes of operation. The control is located in the cockpit at the operator console. The assembly is secured in place by four quarter-turn fasteners on the front panel. All operating controls are mounted on the front panel and all external connectors are located at the rear.

WRA No. 57 is a stick grip assembly which provides for control of the flight surfaces. It consists of a grip assembly, strain gage and connector assembly, electronic assembly and housing assembly. The electronic assembly consists of four amplifiers soldered to a flexible printed tape which terminates at a terminal board. The housing assembly supports an emergency disengage lever and switches.

WRA No. 58 is a unit which provides the operator with the controls necessary for operating various RF recievers. The control is located at the operator console, and is secured in place by five quarter-turn fasteners on the front panel. All operating controls are located on the front panel and all connectors are located at the rear.

WRA No. 59 is a control panel for an armament system. The panel contains the controls and indicators required to monitor and control the selection of stores, attack modes, and release modes. Lifting handles are provided on the front face, top and rear. Operating controls are on the front panel; a total time meter is provided on the rear face of the panel.

WRA No. 60 is a control which provides the operators with the means necessary to operate various RF receivers. The unit is located at the operator console, is secured in place by six quarter-turn fasteners on the front

panel. All operatoring controls are mounted on the front panel and all external connectors are at the rear.

WRA No. 61 is a horizontal situation display. The display consists of a CRT providing an approximately five-inch in diameter display format. It provides a horizontal PPI or horizontal plan display as well as line written symbols. The unit is fan cooled.

WRA No. 62 is a BIT Control which provides the operator with the controls and indicators necessary to initiate and monitor the system built-in-test sequence. The sequence of BIT testing allows the operator to isolate a malfunction to an assembly.

WRA No. 63 is a control converter and is utilized in the system for control configuration of a data terminal set. The unit is comprised of two plug-in/bolt-in printed circuit assemblies and the main chassis. Access to the internal circuitry of the control is provided by means of a removable dust cover.

WRA No. 64 is an indicator which provides the operator with an indication of current system status. It contains 10 legend indicators. The unit is located on the operator's console, and is secured in place by four quarter-turn fasteners on the front panel. All operating indicators are located on the front panel, and all connectors are located at the rear.

WRA No. 65 is a display which presents navigational and other data to the flight crew. The unit contains a CRT that provides a five inch diameter display. The unit is cooled by an internal fan.

WRA No. 66 is a control/display which provides visual and audible signals. It is hard mounted in the cockpit and is cooled by an internal fan. The WRA is provided with an alphanumeric display which indicates the operational status of other system components. Three electrical connectors and an elapsed time indicator are accessible at the rear of the unit.

WRA No. 67 is a display which provides a video presentation of various signals. The unit is located in the cockpit and is mounted vertically on

its left side and consists of a truss grid type of construction upon which the components are mounted. The display tube is installed in the center of the front panel and all operating controls are mounted on the front cover. The unit requires no supplemental cooling.

WRA No. 68 is a control set and contains all controls for operation of a subsystem. The unit is housed in a rectangular, frame-mountable aluminum case. Eight mounting screw holes, located along the top and bottom of the front panel, are provided for securing the unit to the main frame. A vane-axial cooling fan inside the case exhausts air through a ventilation hole in the case bottom when the unit is operating.

WRA No. 69 is a dual control unit for two channels of a communication set. The unit is comprised of five printed circuit plug-in assemblies, two of which are identical, and the chassis. The main chassis contains a printed circuit sideboard for all of the plug-in assemblies and the high dissipation elements of the power supply. The front panel of the WRA contains all the controls for both channels of the system.

WRA No. 70 is a computer control-indicator which serves as an input/output device for the computer. The unit is located at the operator console and is secured in place by eight quarter-turn fasteners on the front panel and two mounting pins at the rear. All controls and indicators are located on the front panel, and all external connectors and an elapsed time meter are located at the rear.

WRA No. 71 is a cockpit mounted control unit consisting of a front panel with aviation red lighting, various manually operated controls, and a logic card chassis. The chassis houses seven printed circuit cards which encompasses all of the low power logic functions. At the rear of the chassis is a separate enclosure where one power and three signal interface connectors are mounted along with the elapsed time meter. Two frequency generator modules are mounted to the removable left plate of the chassis.

WRA No. 72 is a control which provides the operator the ability to insert commands into a computer. Signals, generated within the control, command the computer to perform various functions. The unit is located in the

cockpit at the operator console. It is secured in place by eight quarter-turn fasteners on the front panel. All controls and indicators are mounted on the front panel, and all external connectors are located at the rear . The unit is ambient cooled.

WRA No. 73 is a radar display which receives video information, and processes these inputs to display the selected modes on a direct view storage tube. It also positions the true heading, command heading, range, and time indicators in response to control signals from a computer and a navigation subsystem. The unit is housed in a rectangular aluminum case mounted on a panel in front of the pilot. An elapsed time meter is on the right-hand side of the component. Guide rails along the top rear surface support the component and guide it into place where it is held by three screws that pass through holes in the indicator panel.

WRA No. 74 is a display providing video presentations of various signals. It is located in the cockpit and is supported at the rear by two tapered mounting pins, and at the front by two bolts which pass through the mounting structure and the bottom of the chassis. All operating controls are located on two removable front covers and all connectors and an elapsed time meter are located at the rear of the assembly. It is ambient cooled and hard mounted.

WRA No. 75 is a display which provides the operator with visual indications of information gathered, computed, or processed by various subsystems of the aircraft. The unit is contained in a rectangular aluminum housing having top and bottom access covers. The top cover is fitted with a carrying handle and a cooling air exhaust port. The unit is ambient cooled by means of internal fan and is hard mounted.

WRA No. 76 is a computer control and with its switches, indicators and associated circuits is used to control and monitor system, processor and tape recorder functions. These functions include system reset processor selection, program loading and manual tape control positioning, navigation function control, testing and fault indication. Forced air is used to cool the unit and it is mounted on isolators.

WRA No. 77 is a control which provides the operator with a means of controlling the various equipment functions. Dc voltages are provided at the output of the assembly to implement the control functions, as well as to provide indicator lamp illumination power to the other assemblies. The control is located in the cockpit at the operator console and is secured in place by four quarter-turn fasteners on the front panel. All operating controls are mounted on the front panel and all external connectors are at the rear. It is ambient air cooled.

Power Devices - Power supplies and power switching units comprise this category.

WRA No. 78 is an AC/DC converter power supply which provides unregulated DC to computer memory power supplies and to a control assembly for power failure detection. The unit is shock mounted and is cooled by forced air. It is located in the fuselage.

WRA No. 79 is a power supply containing six voltage regulators which operate off a common power transformer. These regulators supply regulated voltages to various assemblies. The assembly contains an automatic load sensor and protection from excessive voltage output variations. The output of each regulator is sampled by a BIT generator which provides an indication when a power failure occurs. It is isolator mounted and forced air cooled. It is mounted to the aft fuselage.

WRA No. 80 is a power switching unit and consists of a front panel face, a main power switch card chassis and a dual secondary power supply. The power switches control 28 VDC power to several aircraft equipments. The power supply is of modular construction and contains four (4) printed circuit cards and the main frame where a capacitor storage bank and large power dissipating elements are mounted. The unit is forced air cooled and is located in the fuselage above the wing.

WRA No. 81 is a power supply which provides regulated DC for Memory Core Modules. It is forced air cooled and isolator mounted and is located in the fuselage.

WRA No. 82 is a low-voltage power supply and supplies, rectifies, regulates, and controls low voltages for various components. The unit is housed in a rectangular aluminum case with four mounting brackets. Cold-plate heat exchangers are used with forced air cooling to satisfy the unit cooling requirements. The unit is mounted in the nose.

WRA No. 83 is a power supply which provides operating power to other assemblies in the cockpit and contains five voltage regulators which operate off a common power transformer. The power supply is located in the nose right equipment bay of the aircraft and is secured by sliding the assembly onto an isolating tray. Mounts, fastened to the bottom of the isolating tray, latch onto metal brackets on the assembly in order to secure it in place. It is forced air cooled.

WRA No. 84 is a linear power amplifier. The unit provides amplification, gain compensation, and signal limiting of the input RF signal. The WRA contains a power supply and a power amplifier which mount to the main chassis. The power supply is composed of two major functional sections; the high-voltage section and the low-voltage section. Each section contains its own power transformer, control interlock, and monitoring circuits. The unit is isolator mounted and is located in an equipment bay.

WRA No. 85 is a power supply which receives 115 volts, 400 Hz., three phase and 28 volts DC from the aft main circuit breaker panel. It is hard mounted in the left wheel well and has three electrical connectors, an elapsed-time meter, and overheat indicator-reset pushbutton. The power supply consists of a blower, a power supply circuit, and an overheat latching relay.

WRA No. 86 is a 5-volt power supply which is the voltage source for various computer subassemblies. It is forced air cooled and is located in the fuselage equipment bay.

Electro Mechanical Devices - This category consists of items such as sensors, accelerometers, etc.

WRA Nos. 87,.88 and 89 are sensors which provide roll, pitch and yaw inputs respectively to a flight control computer for stability augmentation and aircraft attitude. The electronics are mounted on a printed circuit card. Micro electronics and flexible printed cables are used to reduce size and weight.

WRA No. 90 is a digital data recorder which is a 9-track reel-to-reel unit containing 630 feet of 0.5 inch Mylar-base magnetic tape. The unit is forced air cooled and isolator mounted and is located in the fuselage.

WRA No. 91 is a lateral accelerometer assembly which senses acceleration vectors and provides signals to other flight control components. The unit is a conventional force rebalance unit. Pendulum and suspension are fabricated of quartz fibers and a thin film of silver is vapor deposited over the pendulum and suspension. The unit is located in the fuselage.

Enclosures - This group includes items such as racks and cabinets.

WRA No. 92 is a rack which provides mounting and electrical I/O control and primary power connections to the rest of the system and required interfacing equipments. The entire unit consists only of the required mechanical structural parts, connectors and interconnecting cabling and is located in an equipment bay.

WRA No. 93 is a cabinet which houses various components of a computer set. The unit consists of structural parts, connectors, and interconnecting cabling and is located in an equipment bay.

WRA No. 94 is a rack which provides mounting and electrical I/O connections for a communications subsystem. The unit consists only of the required mechanical structural parts, connectors, and interconnecting cabling. It is located in an equipment bay.

WRA No. 95 is a cabinet which houses various components of a computer subsystem. The unit consists of structural parts, connectors, and interconnecting cabling and is located in an equipment bay.

Table 1 summarizes some of the more significant equipment characteristics and lists them for each WRA. Abbreviations have been used in the columns defining cooling and mounting methods. The following legend describes these:

COOLING METHOD

A = Ambient - Convective cooling - No supplemental air

FA = Forced Air - Supplemental cooling from environmental control system air passes directly over components

FA-O = Forced Air and Oil - Forced air (as above) plus oil-to-air heat exchanger in cold plate

CP = Cold Plate - Supplemental cooling from environmental control system air passes thru cold plate (conductive cooling) not over components

IF = Internal Fan - Integral WRA fan draws in ambient air

MOUNTING METHOD

H = Hard

IS = Isolator Mounted

TABLE 1 - PHYSICAL AND DESIGN CHARACTERISTICS OF SELECTED EQUIPMENT

WRA NO.	FUNCTION	VINTAGE (YEAR OF FINAL DESIGN)	MIL-E-5400 CLASS	COOLING METHOD	MOUNTING METHOD	WEIGHT (POUNDS)	POWER DISSIPATED (WATTS)	VOLUME (CU. IN.)	PIECE PARTS (EXCLUDING MISCELLANEOUS HARDWARE)	PACKAGING DENSITY (PARTS/CU. IN.)	% MICROCIRCUITS
1	RF-REC.-XMTR	1966	2X	FA	IS	28.0	51	1320	1531	1.16	7.64
2	RF-REC.-XMTR	1966	2X	FA-O	H	247.4	7681	7064	1806	0.26	0
3	RF-REC.-XMTR	1970	2	A	H	200	233	7200	2875	0.40	7.37
4	RF-REC.-XMTR	1966	2X	FA	IS	30.0	55	1380	1834	1.33	5.94
5	RF-REC.-XMTR	1968	2	A	H	37.4	50	2413	4338	1.8	2.72
6	RF-REC.-XMTR	1966	2X	FA	IS	36.0	77	1540	2469	1.6	8.34
7	RF-REC.-XMTR	1970	2X	CP	IS	70	620	2002	643	0.32	2.02
8	RF-REC.-XMTR	1966	2X	FA-O	H	244.4	8194	7064	1806	0.26	0
9	RF-REC.-XMTR	1972	1X	FA	IS	22.5	83	721	3307	4.59	5.5
10	RF-REC.-XMTR	1966	2X	FA	IS	34.0	76	1540	2381	1.55	8.65
11	SIG. PROCESS.	1970	2	A	H	1.09	-	48	491	10.23	0
12	SIG. PROCESS.	1970	2	A	H	1.87	-	80	238	2.98	0
13	SIG. PROCESS.	1970	2X	CP	H	32.0	90	1693	3549	2.1	12.43
14	SIG. PROCESS.	1970	1X	FA	H	30.0	137	1731	882	0.51	61.22
15	SIG. PROCESS.	1966	2	A	H	1.6	15	71	51	0.72	0
16	SIG. PROCESS.	1966	2	A	H	9.0	15	308	14	0.05	0
17	SIG. PROCESS.	1966	2X	FA	IS	30.0	69	1729	1292	0.75	15.33
18	SIG. PROCESS.	1966	2	A	H	2.2	15	76	33	0.43	0
19	SIG. PROCESS.	1966	2X	FA	H	63.0	99	3623	989	0.27	4.65
20	SIG. PROCESS.	1968	2	IF	H	31.0	149	1122	1820	1.6	41.81
21	SIG. PROCESS.	1972	1	A	IS	7.9	18	250	633	2.53	3.32
22	SIG. PROCESS.	1968	2	A	H	13.0	25	248	843	3.4	3.2

TABLE 1 - PHYSICAL AND DESIGN CHARACTERISTICS OF SELECTED EQUIPMENT (Continued)

WRA NO.	FUNCTION	VINTAGE (YEAR OF FINAL DESIGN)	MIL-E-5400 CLASS	COOLING METHOD	MOUNTING METHOD	WEIGHT (POUNDS)	POWER DISSIPATED (WATTS)	VOLUME (CU. IN.)	PIECE PARTS (EXCLUDING MISCELLANEOUS HARDWARE)	PACKAGING DENSITY (PARTS/CU. IN.)	% MICROCIRCUITS
23	INTERFACE	1967	1X	FA	IS	53.0	408	2640	2906	1.1	65.11
24	INTERFACE	1967	2X	CP	IS	69	100	4896	2259	0.46	11.51
25	INTERFACE	1966	2	A	H	12.0	12.0	819	804	0.98	13.43
26	INTERFACE	1967	1X	FA	IS	36.0	164	2640	1016	0.39	39.37
27	INTERFACE	1969	2X	CP	H	44	125	2550	1537	0.60	42.29
28	INTERFACE	1966	2X	FA	IS	45.0	145	2665	975	0.37	63.59
29	INTERFACE	1972	1X	FA	IS	28.0	81	939	2048	2.18	23.39
30	INTERFACE	1970	2X	CP	H	19.0	40	1054	629	0.60	26.39
31	INTERFACE	1966	2	A	H	13.0	16.0	819	1200	1.47	6.5
32	INTERFACE	1967	1X	FA	IS	34.0	160	2640	1719	0.65	58.29
33	INTERFACE	1972	1	IF	IS	37.5	150	314	359	1.14	20.89
34	INTERFACE	1967	1X	FA	IS	4.5	-	288	392	1.4	95.92
35	INTERFACE	1966	2	A	H	15.5	70	638	303	0.48	0
36	INTERFACE	1972	1	A	IS	7.4	15	465	497	1.03	16.3
37	COMPUTER	1965	2X	CP	H	48.0	245	1595	4390	2.75	36.0
38	COMPUTER	1970	2	A	H	8.4	41	121	2010	16.61	15.52
39	COMPUTER	1970	2	A	H	8.2	41	121	2363	19.53	13.84
40	COMPUTER	1970	2	A	H	8.3	44	121	1797	14.85	12.3
41	COMPUTER	1967	1X	FA	IS	4.5	33	208	519	2.5	96.72
42	COMPUTER	1967	1X	FA	IS	4.5	33	208	444	2.2	95.72
43	COMPUTER	1967	1X	FA	IS	4.5	33	208	450	2.2	92.67

TABLE 1 - PHYSICAL AND DESIGN CHARACTERISTICS OF SELECTED EQUIPMENT (Continued)

WRA NO.	FUNCTION	VINTAGE (YEAR OF FINAL DESIGN)	MIL-E-5400 CLASS	COOLING METHOD	MOUNTING METHOD	WEIGHT (POUNDS)	POWER DISSIPATED (WATTS)	VOLUME (CU. IN.)	PIECE PARTS (EXECLUDING MISCELLANEOUS HARDWARE)	PACKAGING DENSITY (PARTS/CU. IN.)	% MICROCIRCUITS
44	COMPUTER	1968	2	IF	H	31.5	138	2271	5823	2.6	8.88
45	COMPUTER	1970	1X	FA	H	29.0	137	1742	755	0.43	66.89
46	COMPUTER	1970	2X	FA	H	37.4	250	1165	2311	1.98	28.78
47	COMPUTER	1967	1X	FA	IS	15.0	-	620	1427	2.3	15.0
48	COMPUTER	1970	2X	FA	IS	30.5	245	1013	1851	1.83	50.73
49	COMPUTER	1970	1X	FA	H	34.0	167	1741	701	0.40	53.32
50	COMPUTER	1966	2X	FA	IS	47.5	560	4158	6678	1.61	40.76
51	COMPUTER	1969	1	A	IS	20.0	80	504	1345	2.68	25.8
52	COMPUTER	1967	1X	FA	IS	23.0	132	1550	778	0.50	16.58
53	DISPLAY & CONTR.	1970	2	A	H	3.3	30	-	31	-	0
54	DISPLAY & CONTR.	1966	2	A	H	10.0	58	589	628	1.07	28.34
55	DISPLAY & CONTR.	1969	2	A	H	22.0	36	1121	233	0.21	0
56	DISPLAY & CONTR.	1966	2	A	H	2.0	5	140	45	0.32	0
57	DISPLAY & CONTR.	1970	2	A	H	3.9	28	28	28	1.0	7.14
58	DISPLAY & CONTR.	1966	2	A	H	5.0	7	290	63	0.22	0
59	DISPLAY & CONTR.	1968	2	A	H	58.0	65	2485	1963	0.79	11.46
60	DISPLAY & CONTR.	1966	2	A	H	4.0	9	357	56	0.16	3.57
61	DISPLAY & CONTR.	1970	2	IF	H	16.5	150	672	634	0.94	8.52
62	DISPLAY & CONTR.	1966	2	A	H	3.4	3	247	59	0.24	0
63	DISPLAY & CONTR.	1972	1	A	H	2.8	30	130	133	1.0	0
64	DISPLAY & CONTR.	1966	2	A	H	1.0	8	83	17	0.21	0

TABLE 1 - PHYSICAL AND DESIGN CHARACTERISTICS OF SELECTED EQUIPMENT (Continued)

WRA NO.	FUNCTION	VINTAGE (YEAR OF FINAL DESIGN)	MIL-E-5400 CLASS	COOLING METHOD	MOUNTING METHOD	WEIGHT (POUNDS)	POWER DISSIPATED (WATTS)	VOLUME (CU. IN.)	PIECE PARTS (EXCLUDING MISCELLANEOUS HARDWARE)	PACKAGING DENSITY (PARTS/CU. IN.)	% MICROCIRCUITS
65	DISPLAY & CONTR.	1970	2	IF	H	16.3	150	672	549	0.82	9.29
66	DISPLAY & CONTR.	1968	2	A	H	3.4	15	135	605	4.5	0
67	DISPLAY & CONTR.	1966	2	A	H	40.0	169	3257	790	0.24	21.9
68	DISPLAY & CONTR.	1970	1A	IF	H	36	121	2246	535	0.24	21.31
69	DISPLAY & CONTR.	1972	1	A	H	6.0	25	130	842	6.48	3.56
70	DISPLAY & CONTR.	1966	2	A	H	17.0	65	8721	1041	0.12	20.9
71	DISPLAY & CONTR.	1970	2	A	H	13.8	31.5	1147	1460	1.27	37.19
72	DISPLAY & CONTR.	1966	2	A	H	7.0	53	486	150	0.31	0
73	DISPLAY & CONTR.	1970	1A	IF	H	40.0	220	1953	591	0.30	2.2
74	DISPLAY & CONTR.	1966	2	A	H	25.0	74	1530	447	0.29	2.46
75	DISPLAY & CONTR.	1970	1A	IF	H	38.0	270	1866	565	0.30	3.36
76	DISPLAY & CONTR.	1967	1X	FA	IS	16.0	15	2240	616	0.28	11.69
77	DISPLAY & CONTR.	1966	2	A	H	3.0	67	197	55	0.28	0
78	POWER SUPL. & SW.	1967	1X	FA	IS	22.0	96	1548	148	0.10	0
79	POWER SUPL. & SW.	1966	2X	FA	IS	52.0	680	1370	655	0.48	0.31
80	POWER SUPL. & SW.	1970	2	A	H	20.5	102	986	938	0.95	7.14
81	POWER SUPL. & SW.	1967	1X	FA	IS	7	127	480	481	1.0	0
82	POWER SUPL. & SW.	1970	2X	CP	H	36.0	265	1002	750	0.75	1.2
83	POWER SUPL. & SW.	1966	2X	FA	IS	40.0	320	1370	237	0.17	1.27
84	POWER SUPL. & SW.	1972	1	A	IS	54.5	1540	1053	1748	1.66	3.89

TABLE 1 - PHYSICAL AND DESIGN CHARACTERISTICS OF SELECTED EQUIPMENT (Continued)

WRA NO.	FUNCTION	VINTAGE (YEAR OF FINAL DESIGN)	MIL-E-5400 CLASS	COOLING METHOD	MOUNTING METHOD	WEIGHT (POUNDS)	POWER DISSIPATED (WATTS)	VOLUME (CU. IN.)	PIECE PARTS (EXCLUDING MISCELLANEOUS HARDWARE)	PACKAGING DENSITY (PARTS/CU. IN.)	% MICROCIRCUITS
85	POWER SUPL. & SW.	1968	2	IF	H	7.3	64	156	144	0.92	2.78
86	POWER SUPL. & SW.	1967	1X	FA	IS	8.0	196	428	278	0.65	3.6
87	ELECTRO-MECH.	1970	2	A	H	1.72	41	39.9	85	2.13	7.06
88	ELECTRO-MECH.	1970	2	A	H	1.72	41	39.9	86	2.16	8.14
89	ELECTRO-MECH.	1970	2	A	H	1.72	41	39.9	143	3.58	6.29
90	ELECTRO-MECH.	1967	1X	FA	IS	35.0	85	1450	902	0.62	38.69
91	ELECTRO-MECH.	1970	2	A	H	0.77	30	4	3	0.75	0
92	RACK & CAB.	1972	1X	FA	IS	18.0	-	1090	4	0.004	0
93	RACK & CAB.	1967	1X	FA	IS	77.0	-	11,800	52	0.004	0
94	RACK & CAB.	1972	1X	FA	IS	24.7	-	1190	7	0.006	0
95	RACK & CAB.	1967	1X	FA	IS	161.0	-	25,700	45	0.002	0

SECTION III

ENVIRONMENTAL ANALYSIS

3.1 Demonstration

The Advisory Group on Reliability of Electronic Equipment (AGREE) was formed in 1952 by the Defense Department's Research and Development Board to "monitor and stimulate interest in reliability and recommend measures that would result in more reliable electronic equipment." In 1957, after two years of study, the project was completed and a report issued[1]. The results of Task Group 3 (there were nine groups formed) studies included recommendations for measuring MTBF and provided details of; sample selections, environmental specifications and test, procedures, data handling and statistical techniques. The Group restricted environmental conditions to vibration, temperature, on-off cycling and input voltage cycling. Other environments such as humidity, altitude and shock were purposely omitted in the belief that vibration and temperature would also reveal basic faults sensitive to the other environments. Current information indicates that the premise was incorrect and that failure modes due to humidity/altitude exposure are not duplicated by vibration/temperature.

The environments originally selected by Task Group 3 were chosen for the following reasons:

"Temperature: The temperature test is intended to approximate the survice conditions under which the equipment will be required to operate."

"Vibration: This is not intended to be the most severe condition encountered but is felt adequate to show up workmanship items such as loose solder joints, loose parts such as screws, bits of wire, etc. This test is to be performed with the equipment mounted solidly on the vibration table without shock mounts."

(1) "Reliability of Military Electronic Equipment," Advisory Group on Reliability of Electronic Equipment (AGREE), Office of The Assistant Secretary of Defense, Washington, D.C. 4 June 1957.

"On-Off Cycling: This test is primarily to give the equipment a temperature cycle, causing the entire equipment to 'breathe,' expand and contract, be exposed to the surges of starting electrical power, plus checking actual operation."

"Input Voltage: Varying the input voltage both above and below the normal rated voltage places a strain on the various circuits and, since this is a normal condition in service, will reveal many weak conditions."

Table 2 presents the stress levels/environmental conditions recommended by the group.

This represented the beginning of reliability demonstration testing and the requirements originally recommended were incorporated into specification MIL-R-26667 (USAF), followed by MIL-R-23094 (WEP) and finally, the MIL-STD-781 series currently in effect. While the thermal exposure prescribed may be adequate, the vibration requirement and the lack of other environments, e.g., humidity, during the test period, are unrealistic based on data and studies performed by Grumman Aerospace Corp., the Air Force Flight Dynamics Lab at Wright-Patterson Air Force Base and others. Certainly the vibration prescribed for this test does not duplicate the field environment for jet aircraft (ref. 4). Further the constraint of testing at one non-resonant frequency immediately precludes detection of problems at other frequencies (ref. 5). Additionally, for certain equipments, the effects of exposure to environment such as altitude and humidity may not be apparent in a "qualification" test but may be time dependent and require repeated application (simulated service conditions) before a reasonable assessment can be made.

Selected Equipments

Each of the equipments selected for this study were subjected to a reliability demonstration test. While the majority of the units were tested to an environmental profile of MIL-STD-781 or MIL-R-23094 (WEP) (ref. 2,6) which included only thermal cycling and fixed frequency vibration (see Fig. 1), certain items were evaluated in accordance with special environmental profiles, intended to simulate operational conditions. An example of this variation is presented in Figs. 2 to 4.

TABLE 2 AGREE ENVIRONMENTS

STRESS LEVEL / ENVIRONMENTAL CONDITIONS	L (LIGHT)	M (MEDIUM)	H (HIGH)	X (EXTREME)
Temperature	25° ± 5°C (68°F to 86°F)	40° ± 5°C (95°F to 113°F)	(Chamber) -54°C to +55°C (-65°F to 130°F)	-65°C to +71°C (-85°F to 160°F)
Vibration	None	25± 5 cps at 2g	Same as M	Same as M
On-Off Cycling	3 hrs. "on" plus long enough to stabilize at both high and low temp. by actual measurement.	Same as L	Same as L	Same as L
Input Voltage	Nominal	Max. specified permissible Voltage +0 - 2%	Same as M	Same as M

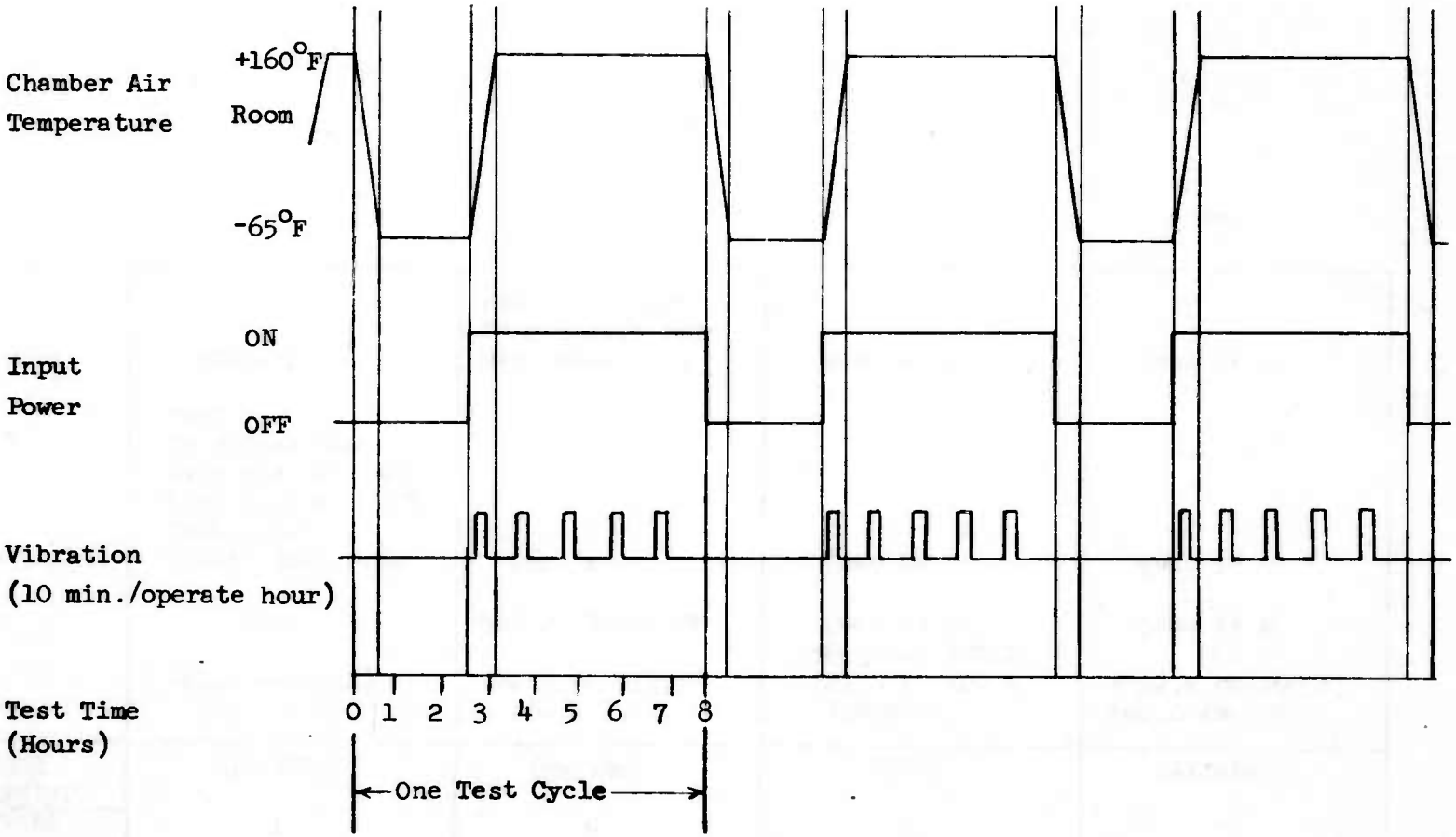


FIGURE 1 TYPICAL MIL-STD-781 PROFILE

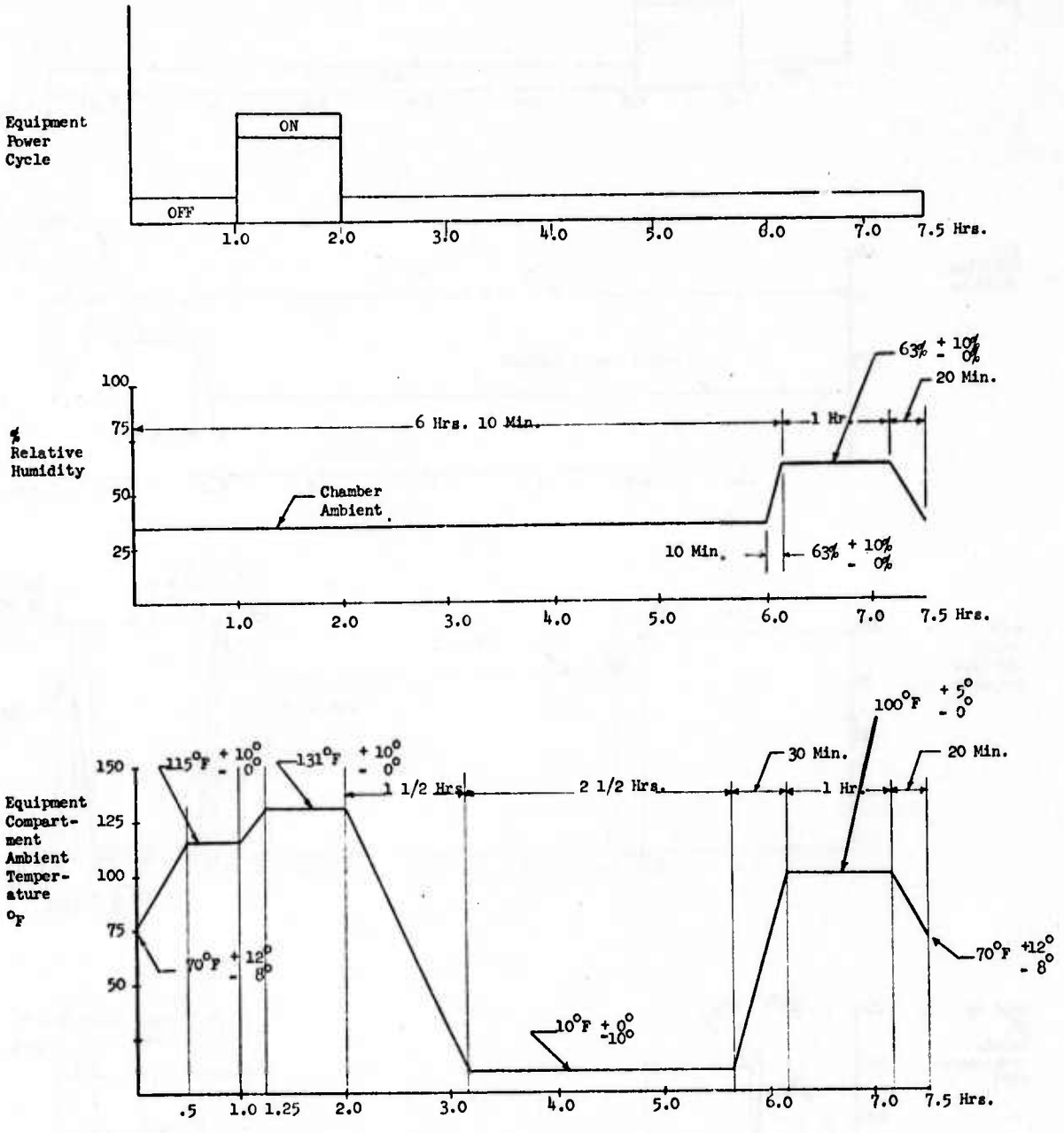


FIGURE 2 TEST CYCLE A - AMBIENT COOLED EQUIPMENT

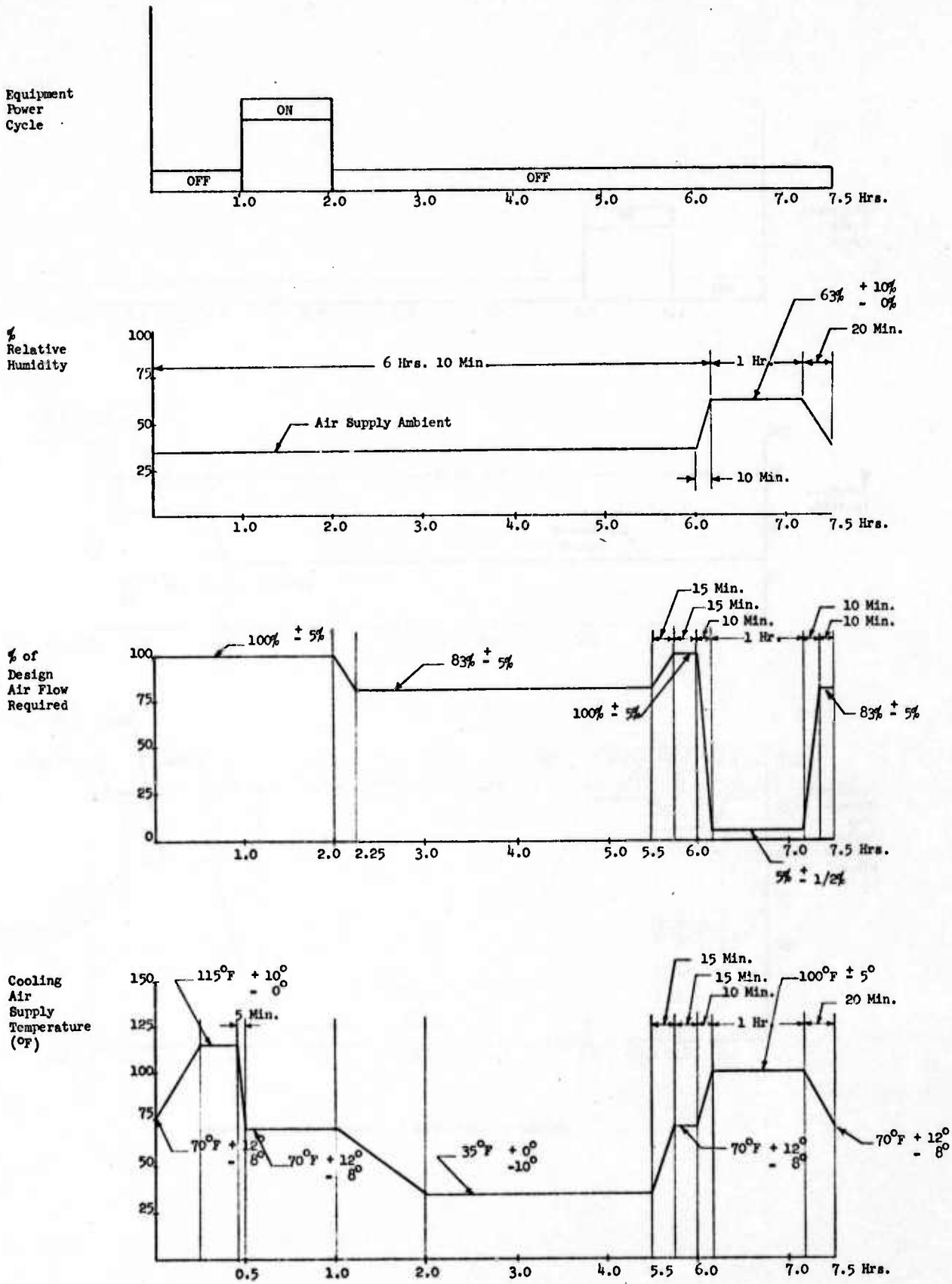


FIGURE 3 TEST CYCLE A - FORCED AIR COOLED EQUIPMENT

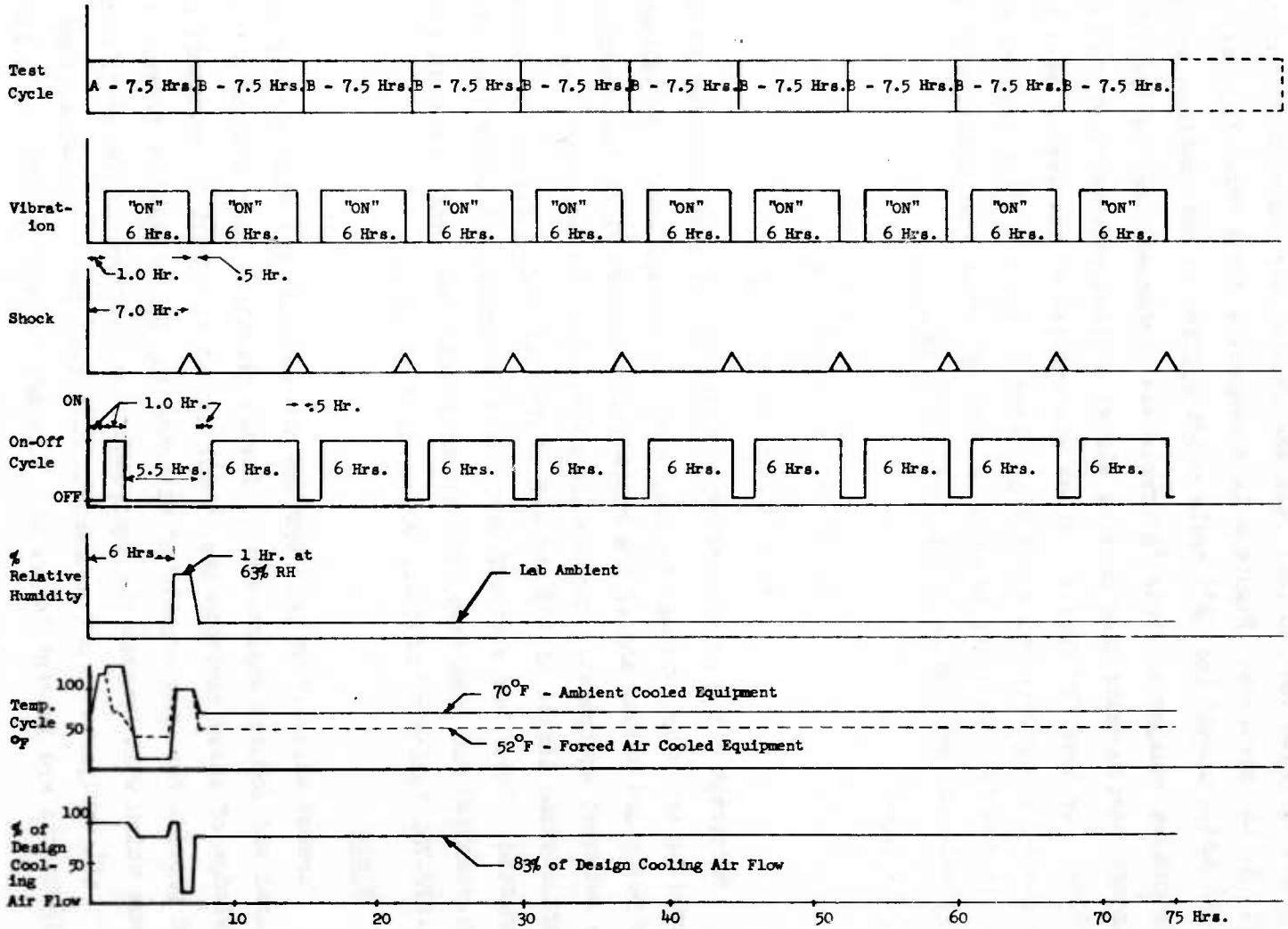


FIGURE 4 COMPOSITE ENVIRONMENTAL TEST CYCLE

Figure 2 depicts the test cycle (A) that was applied to ambient cooled equipment and indicates the power, humidity and compartment temperature variations. Figure 3 presents a similar cycle (A) applied to forced air cooled equipment. Note that in this case the cooling air temperature was varied as well as the air flow. Figure 4 is a composite cycle which includes vibration, shock and a second (or "B") cycle which applied to both ambient and forced air cooled equipment. This "B" cycle was performed under benign lab thermal ambient environments plus cooling air at a fixed rate and each "A" cycle was followed by nine "B" cycles. Shock was applied at the end of each cycle at levels of 4.0 g vertical and 2.8 g lateral. The vibration environment was maintained for six hours of each "A" and "B" cycle and consisted of sweeps 10-500-10 Hz. and dwells at 73.6 and 147.2 Hz.

Levels were:

10 -41 Hz. at 0.018" D.A.

41 - 500 Hz. at $\pm$ 1.5 g

Paragraph 5.2.4 of MIL-STD-781B indicates that, if required by the procuring activity, voltage cycling shall be accomplished. No voltage cycling was performed during any of the reliability demonstration tests conducted on the selected equipment. Input voltages were maintained within the equipment specification limits of +5% and -2% of nominal during all of the tests conducted. Power was shut off periodically during each cycle (per MIL-STD-781 requirements) and then reapplied but no attempt was made to run at the MIL-STD-781 limits of nominal, 90% or 110% of nominal.

3.2 Field

Current aircraft weapons systems are exposed to a wide variety of natural and induced environments. Design practices must include detailed knowledge of these environments, their potential effect on equipment and then provide hardware capable of withstanding the effects or present a scheme which will protect the equipment from exposure to the environment. Since all equipment is not exposed to each environment and since some environments are present longer and have more degrading effects, a listing

(Table 3) of all the environments that a black box might be exposed to was prepared to serve as a gross filter. This tabulation was then screened in terms of Grumman, industry and Government experience to establish the particular environments which are known to degrade equipment performance and which were to be used in this study.

The study performed by Grumman for the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base (ref. 1), plus a review of current lab and field data, indicate that of the total possible environments existing, seven are responsible for essentially all of the failures related to environmental causes. Figure 5 depicts the distribution of failures as a function of these environments. Temperature, vibration and moisture accounted for 86% of the environmental failures. It was therefore decided to concentrate the major effort on these three environments and, to a lesser degree, evaluate the impact of sand and dust, altitude and shock (salt spray was included as part of moisture for this study). Preliminary investigations indicate that failures due to shock and sand and dust were minimal and these are not addressed in this report. Further investigations will be conducted during the remaining study period. Also at this point in time there is no evidence (with the exception of temperature/ humidity) that a synergistic effect exists which may seriously degrade equipment performance. Grumman experience includes results of overstress testing performed on over fifteen WRA's wherein temperature, vibration and shock were applied first singly and then in combination. While numerous failures were revealed during the individual tests, no additional failures (or failure modes) were detected during combined testing. In some cases the combination could result in less failures (a synergism in reverse) than single exposure (ref. 7). This effect will be further evaluated during the remaining study period.

Field environmental data was reviewed in some detail for temperature, vibration, moisture and altitude and a discussion of the results is presented in the following paragraphs:

3.2.1 Temperature and Cooling Air

The information on thermal field environments for the aircraft involved in this study are a combination of analyses and measured data.

TABLE 3 - POTENTIALLY DEGRADING ENVIRONMENTS AND PROBABLE EFFECTS ON AVIONIC EQUIPMENT

ENVIRONMENT	CONDITION (TYPE)	HOW MANIFESTED	PRINCIPAL EFFECT	PROBABLE FAILURE MODE
Temperature	Steady State - High	Ambient exposure Equipment induced Mission induced (certain steady state phases)	Aging Insulation deterioration Oxidation Expansion Reduction of viscosity Softening Evaporation, drying Chemical changes	Alteration of properties Shorting Rust Physical damage, increased wear Loss of lubrication in bearings, seizing Physical breakdown Dielectric Loss
	Steady State-Low	Ambient exposure Mission induced for certain phases and certain equipment Note: This condition is minimal. Encountered at present active bases, and in some flight modes	Contraction Viscosity increase, embrittlement, ice formation	Wear, structural failure, binding Loss of lubricity Structural failure, cracked components Structural failure, alteration of electrical properties Loss of resilience - seal leaks
	Thermal Cycling	Ground operation Mission operation and profile environment control system limits	Decrease in component reliability	Repeated stress variation causes mechanical failure of components solder joints, lifting of I/C's from base material
	Thermal Shock	Mission profile Geography and season of year	High temperature gradients	Mechanical failure • Cracks • Rupture

TABLE 3 - POTENTIALLY DEGRADING ENVIRONMENTS AND PROBABLE EFFECTS ON AVIONIC EQUIPMENT (Continued)

ENVIRONMENT	CONDITION (TYPE)	HOW MANIFESTED	PRINCIPAL EFFECT	PROBABLE FAILURE MODE
Vibration	Sine	Engine induced-Propeller aircraft	Force variation Periodic variation (motion is harmonic) • Mechanical stress • Fatigue	Structural failure Increased wear Interference with proper operation Relay, switch contact chatter
	Random	Engine Induced-Jet Aircraft Acoustic Noise Turbulence (Aeronautical Buffeting) Gunfire	Force variation - Random variation of amplitude and frequency Pressure loads and force • Mechanical stress • Fatigue	Same as Sine
Contamination	Sand and Dust	Sand lifted by wind. Dust particles present above desert areas and in atmosphere throughout world. Note: Confined to 10K' (maximum conditions at 1500')	Abrasion Clogging Sticking	Erosion of surfaces. Increased wear (especially in combination with moisture - water, oils, greases). Functional interference, arcing of high-voltage electrodes.
	Atmospheric Pollution	Chimney smoke Milling operations Volcanic action	Same as Sand and Dust, except formation of acids-in combination with mist.	Same as Sand and Dust plus extensive effects of acids
Explosive Atmosphere	Combustibles	Presence of combustible (fuel) gases inside equipment at temperature, R.H., & atmospheric pressure which favor explosion	Structural, etc. damage and/or complete destruction	Function interference. Loss of aircraft
Shock		Arrested Landing - Catapult Launch	Same as vibration	Same as vibration

TABLE 3 - POTENTIALLY DEGRADING ENVIRONMENTS AND PROBABLE EFFECTS ON AVIONIC EQUIPMENT (Continued)

ENVIRONMENT	CONDITION (TYPE)	HOW MANIFESTED	PRINCIPAL EFFECT	PROBABLE FAILURE MODE
Acceleration	Steady State	Catapult Launch - Maneuvers Due Mission Profile	Mechanical stress Induced switching, etc.	Loss of mechanical strength Interference of (relays, switchings, centrifugal devices)
Fungus		High R. H., optimum temperature (100°) plus nutrient material. (Tropical Environment)	Attack on organic materials	Loss of dielectric strength Electrical degradation
Bench Handling	Shock	Handling during shipping, installation, repairs, etc.	Structural damage Mechanical stress	Component damage, functional interference Electrical degradation (shorts, misalignment).
Atmospheric Electricity	Static	Autogenous-Rubbing of particles (snow, dust, sand) against vehicle surface. Exogenous-High potential gradients in atmosphere.	Personnel shock Combustibles- ignition Arcing Radio interference	Interference with duty Explosion (See explosive atmosphere) Shorting - component damage primarily semiconductors Mission interference
	Lightning	Difference in electrical potential between ground and clouds or cloud to cloud (within thunder clouds)	Surface damage; complete desctruction of non-metallic parts. Electrical damage	Loss of control surfaces Explosion of radomes, windshields. Current fed to electronic equipment from antenna causes equipment and component damage.
Radiation	Solar (Sunshine)	Heat energy leaving sun	See Temperature	See Temperature
	Cosmic	Sun, other sources. These are rays with enough energy to reach earth	Short term ionization. Generally no serious effects.	Spurious electrical pulses which may affect computers.

TABLE 3 - POTENTIALLY DEGRADING ENVIRONMENTS AND PROBABLE EFFECTS ON AVIONIC EQUIPMENT (Continued)

ENVIRONMENT	CONDITION (TYPE)	HOW MANIFESTED	PRINCIPAL EFFECT	PROBABLE FAILURE MODE
	Nuclear	Nuclear engines, nuclear reactors, nuclear weapons	Since frequency of occurrence is almost nil, this environment will not be considered.	
TRANSPORTATION	Land Truck Rail Air Conditioned compartment Non-conditioned compartment Sea	Shipment of equipment Delivery of equipment Shipment of equipment.	In general the effects can be established from other basic environments i.e., temperature, altitude, vibration, shock, etc. However, for air transport at 50K', a temperature of-105°F can be experienced per AT 70-38 (Army regulation)	See individual environmental Temperature Altitude Vibration Shock Susceptible equipment can be physically damaged even in the non-operating-storage state.
Moisture	Humidity	Water content of air	Galvanic action Microbiological growth Electrolysis Moisture absorption Corrosion	Loss of electrical properties Interference with function, swelling, rupture Dissolution of metals Increased wear Fungus growth and material damage
	Condensation	Variation in altitude causes condensation on structure and within equipment.	Same as Humidity	Same as Humidity
	Rain	Precipitation of water vapor	Same as Humidity, plus physical stress erosion	Same as Humidity, plus physical damage erosion

TABLE 3 - POTENTIALLY DEGRADING ENVIRONMENTS AND PROBABLE EFFECTS ON AVIONIC EQUIPMENT (Continued)

ENVIRONMENT	CONDITION (TYPE)	HOW MANIFESTED	PRINCIPAL EFFECT	PROBABLE FAILURE MODE
	Icing	Liquid droplets present at sub-freezing temperatures. Supercooled clouds.	Physical stress Added weight changes in aerodynamic profile	Structural failure Physical and electrical property changes Loss of performance or even entire aircraft. Interference with certain functions.
	Hail	Developed in thunderstorms	Physical damage	Dents, cracks, ingestion
	Salt Fog Salt Spray	Salt in suspension in water droplets, coastal areas, ocean atmosphere. Shipboard environments, high winds, etc., creating salt water spray.	Corrosion Electrolysis	Increased wear Dielectric loss Structural defects • Surface deterioration Increased conductivity
Pressure	Ambient	Altitude Variation	Outgassing force due to pressure differential. Reduced dielectric strength of air	Loss of lubricants Structural damage Corona discharge causes ozone formation and damages parts, causes insulation breakdown. Ozone oxidizes, rubber and synthetics also forms corrosive acids.
	Explosive Decompression	Instantaneous loss of cabin compartment pressure	Large instantaneous pressure difference.	Mechanical damage and pressure shock to equipment.
	Wind	Differences in atmospheric density, producing horizontal difference in air pressure	Causes other environment to become dangerous. Sandstorms, blizzards alters flight paths of vehicles.	Primarily affects aircraft level. On ground could affect ground support equipment.

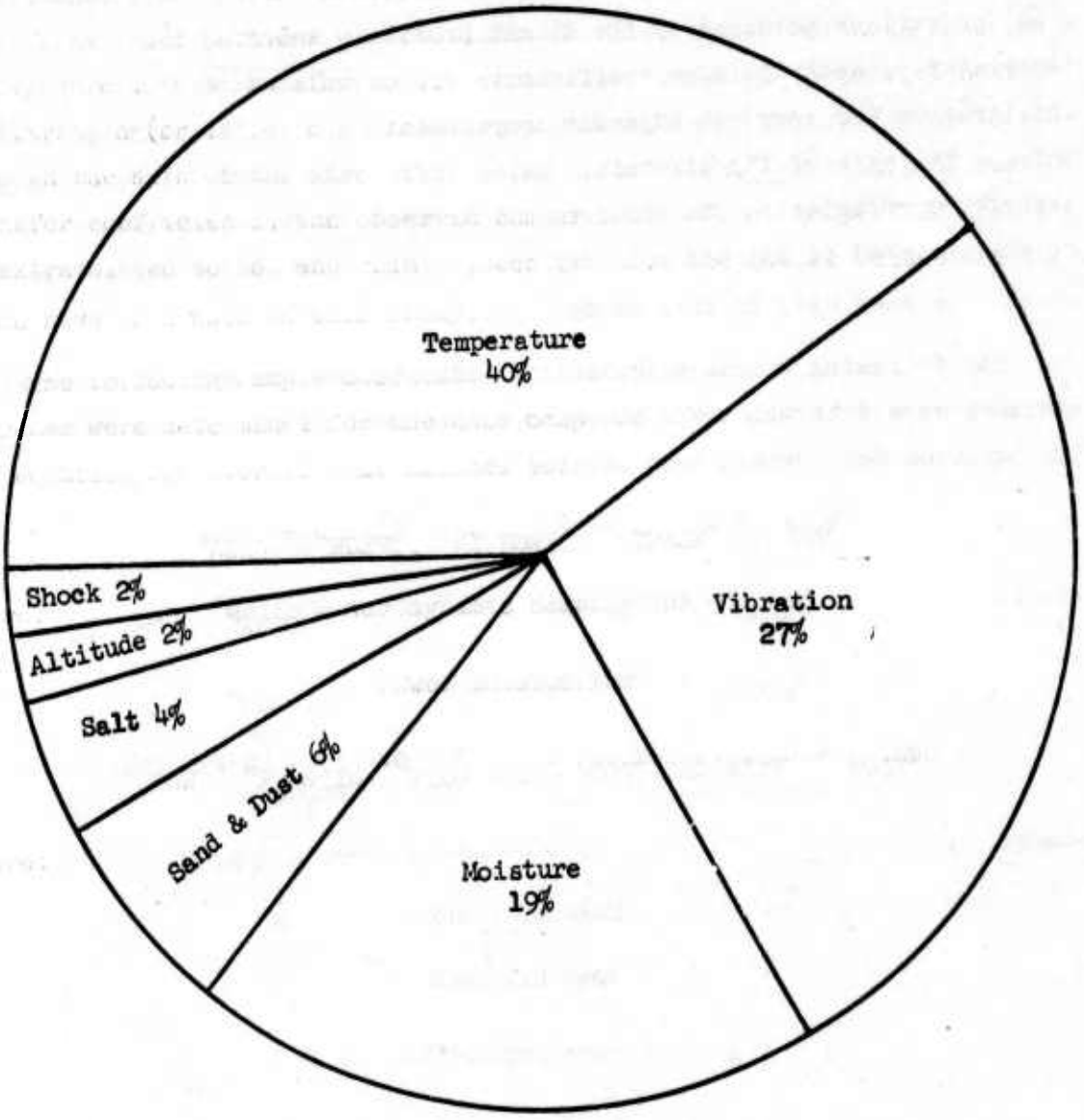


FIGURE 5 DISTRIBUTION OF ENVIRONMENTALLY RELATED FIELD FAILURES

Ambient Temperatures

Compartment ambient temperatures are measured during the flight test program for various portions of the flight profile. Based on these measured temperatures, heat transfer coefficients are calculated to provide heat infiltration (or loss) to adjacent compartments and infiltration or loss through the skin of the aircraft. Using these calculated values of heat transfer coefficients, the observed compartment ambient temperature can then be extrapolated to hot and cold day conditions. The latter values are those which have been used in this study.

The following sample calculations indicate how the ambient temperature extremes were determined for the nose compartment of one of the study aircraft. The equation for overall heat balance is:

$$Q_{AERO} + Q_{ELECT.} + Q_{FLOW\ IN} - Q_{FLOW\ OUT} = 0$$

where: Q_{AERO} = Aerodynamic Heating (or Cooling)

$Q_{ELECT.}$ = Power Dissipation

$Q_{FLOW} = Q_{FLOW\ IN} - Q_{FLOW\ OUT}$ = Thermal Flow Energy Into or Out of Compartment

$= \dot{m}\ Cp\ (T_{IN} - T_{COMPT})$

where: $\dot{m}$ = Mass Flow Rate

C_p = Specific Heat

T_{IN} = Flow Temperature In

$T_{COMPT.}$ = Compartment Temperature

Substituting for Q_{FLOW}:

$$Q_{AERO} + Q_{ELECT.} + \dot{m}\ C_p\ (T_{IN} - T_{COMPT.}) = 0$$

Values for each of the equation terms were obtained as follows:

- Q_{AERO} was obtained from flight data heat load curves which are a function of ambient temperature, Mach number and altitude.
- $Q_{ELECT.}$ is the measured (laboratory) power dissipation of the avionic equipment located in the compartment.
- Q_{FLOW} was obtained from laboratory tests of the actual flight cooling system.

Utilizing the values so obtained, $T_{COMPT.}$ was then calculated for the nose compartment. For the maximum compartment temperature (sea level and V_{MAX} conditions), the heat load curves for extreme hot day conditions were used to determine Q_{AERO}.

SOLVING:

$$0 = 7880 \text{ BTU/HR} + 5620 \text{ BTU/HR} + 2160 \text{ \#/HR} \times 0.25 \frac{\text{BTU}}{\text{\#-}^{o}\text{F}} (80^{o}\text{F} - T_{COMPT})$$

FROM WHICH:

$$T_{COMPT.} = +105^{o}\text{F}$$

The minimum compartment temperature (altitude and V_{MIN} conditions*) was calculated in an identical manner using flight data for Q_{AERO} for an extreme cold day. The above type of analysis applies to compartments which have no active means of temperature control. For a controlled compartment (such as the cockpit), the design limits are given and have been verified during the flight test program.

Among other variables, the thermal environment experienced by a black box is a function of mission profile and location within the aircraft. One common phenomenom which has been observed is that all compartment ambient temperatures, experience to some extent, a thermal cycling effect whose frequency is much greater than that required by MIL-STD-781. To illustrate this, two typical curves are presented for compartment temperature variations as a function of altitude and speed. Figure 6 shows thermal variations within a fuselage compartment of a turbo jet aircraft. It can be seen that, although for steady state conditions of speed and altitude, there is a corresponding change

* V_{MIN} is minimum velocity to preclude aircraft stall.

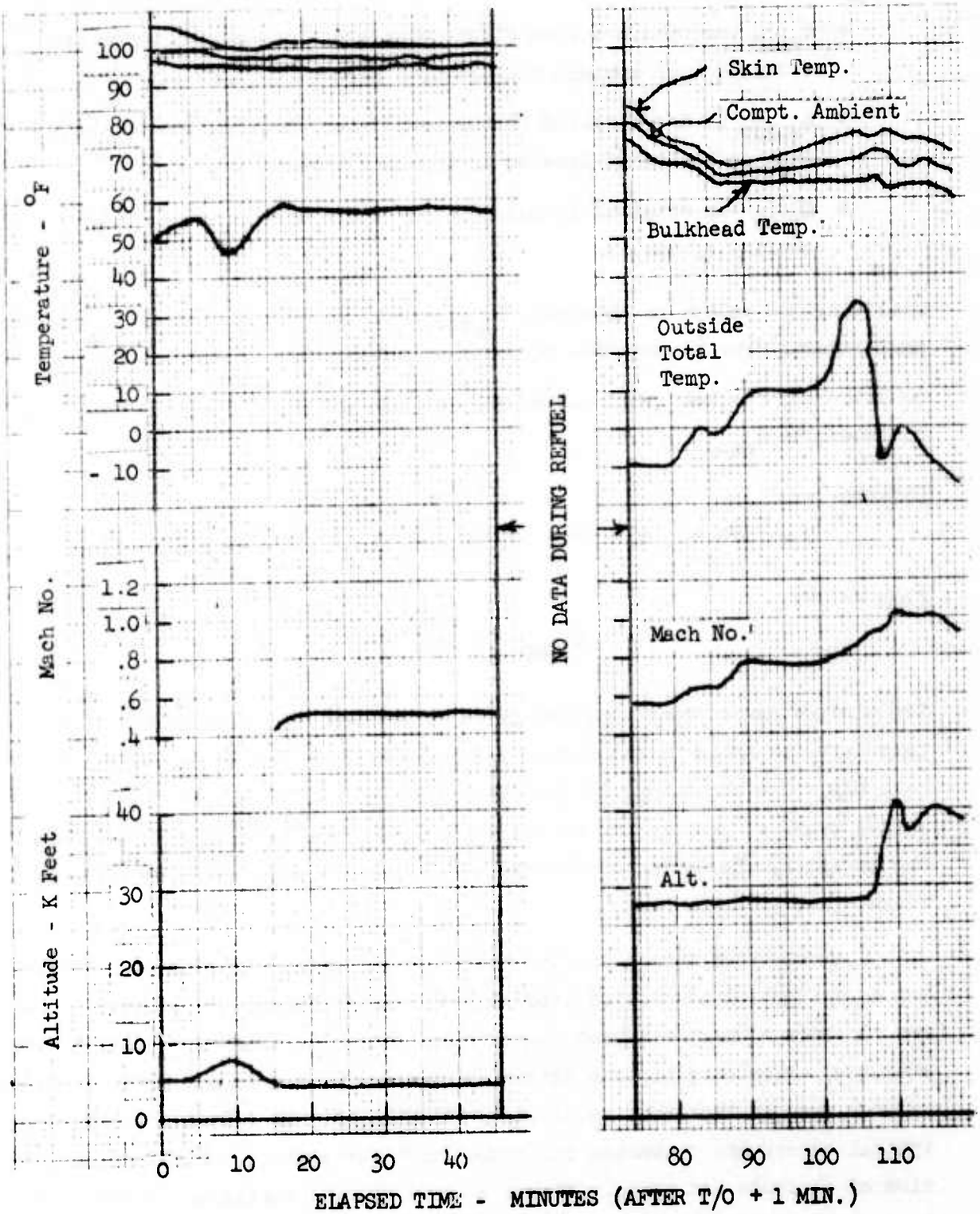


FIGURE 6 PRE-AMP COMPARTMENT TEMPERATURE

in the absolute value of compartment temperature, it is only when rapid variations of these parameters occur that thermal cycling effects become apparent.

Figure 7 represents the nose compartment thermal profile for a different turbo jet aircraft and indicates a wide variation in temperature for changing flight conditions. In this case the two cyclical variations are more apparent and occur in periods of 30 minutes and 15 minutes respectively. By comparison, the thermal cycle presently defined by MIL-STD-781 encompasses a six hour period.

Cooling Air Flow Rate

Forced air cooled boxes effectively shield the electronic components from changes in compartment ambient temperature. The operating temperatures of the components within the box are usually established by the temperature and flow rate of the cooling air.

The cooling air flow rates are based on measured data taken during laboratory tests and later verified in the flight test program. Separate tests were conducted to determine the performance of the air conditioning pack and flow splits to the various avionics boxes. The flow required for each forced air cooled box is a function of the cooling air supply temperature. The worst case condition for each box is determined and the required flow to the box is supplied. At all other conditions, the box will receive a flow in excess of that required.

The flows established in the laboratory testing are then verified in actual flight testing. A typical plot of cooling air temperature is provided in Figure 8. The data represents two minutes of dynamic manuvering during a test flight of a turbo jet aircraft and shows that, although the cooling air supply temperature is controlled within specified limits, some thermal transients are evident. This type of variation is characteristic of environmental control systems.

Tables 4 and 5 present the lab and field thermal environments for each black box. Table 4 includes the ambient air temperature parameters and Table 5 presents the pertinent cooling air and thermal parameters for those WRAs requiring suplemental cooling. These values were obtained in the manner

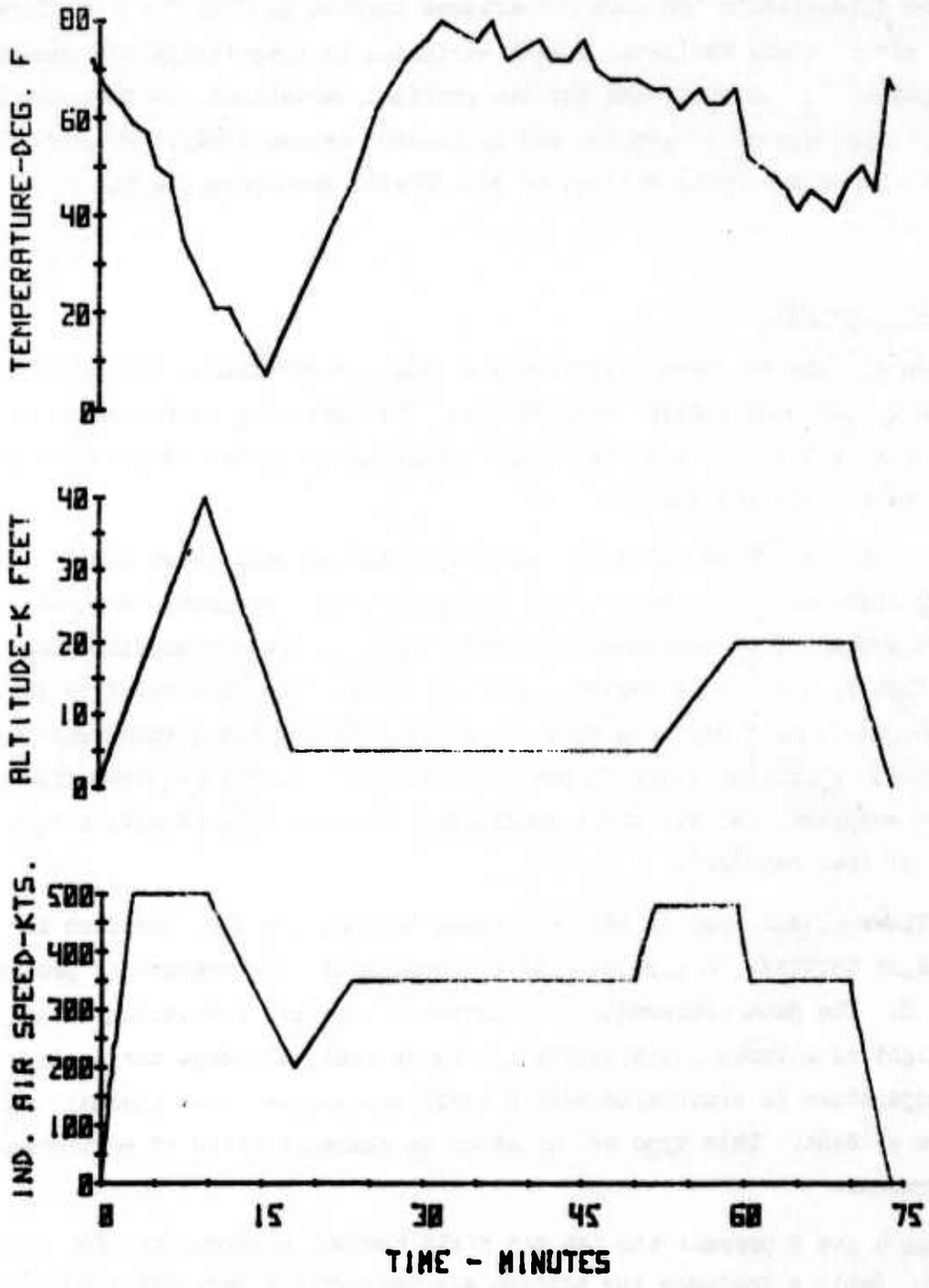


FIGURE 7 NOSE COMPARTMENT TEMPERATURE

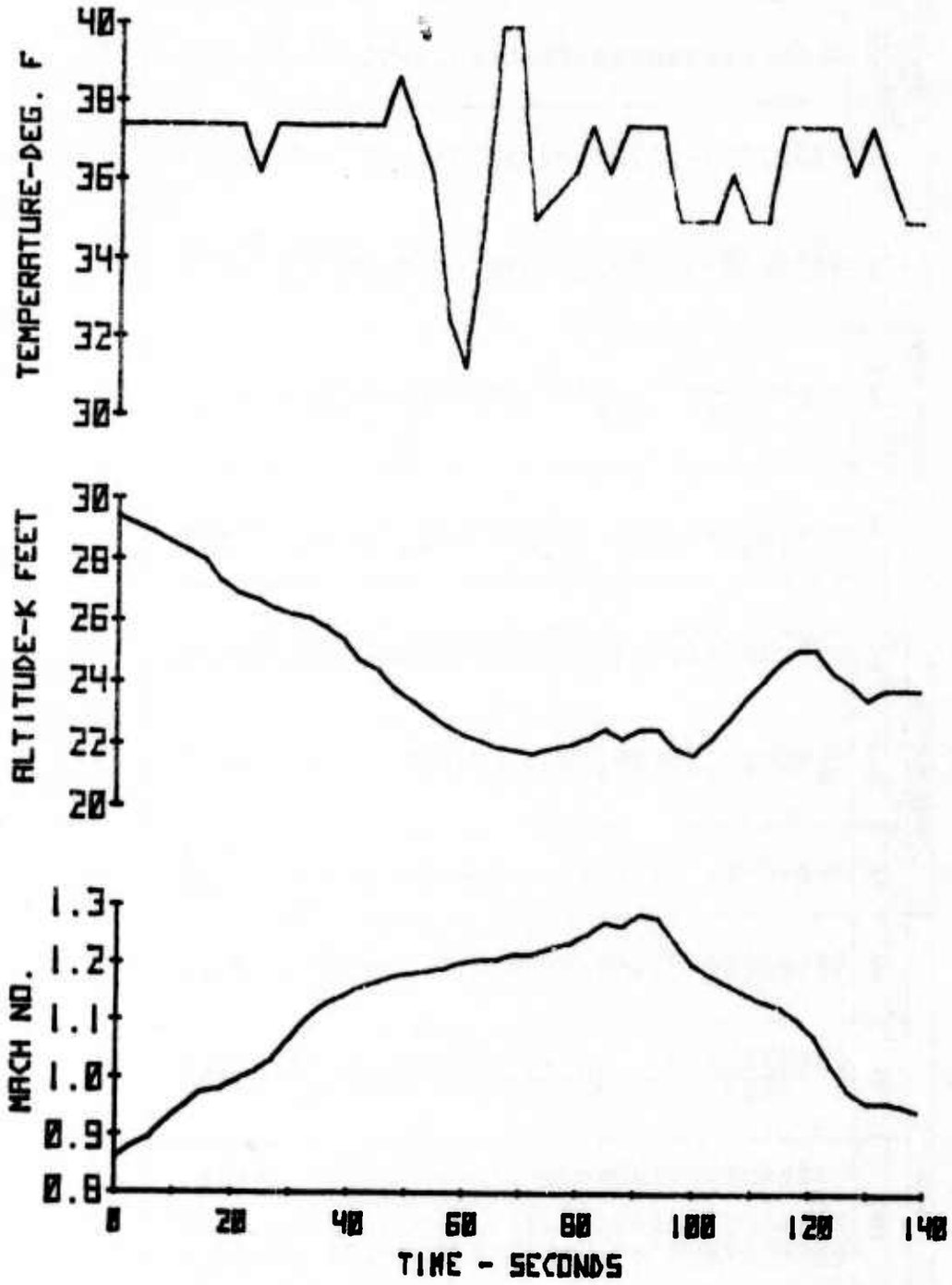


FIGURE 8 COOLING AIR TEMPERATURE

TABLE 4 AIR AMBIENT TEMPERATURE PARAMETERS

WRA NO.	RANGE °F		Δ °F		DURATION-HI-TEMP. HRS.		Δ	DURATION-LO-TEMP. HRS		Δ	RATE OF CHANGE °/MIN.		Δ
	LAB	FIELD	MIN	MAX	LAB	FIELD	HRS.	LAB	FIELD	HRS.	LAB	FIELD	°/MIN.
1	-65 to +131	+50 to +160	(-)115	+29	0	5.6	+5.6	19.4	0	-19.4	9	10	+1.0
2	-65 to +106	+50 to +170	(-)115	+64	0	10.8	+10.8	36	10.8	-25.2	9.0	10	+1.0
3	-65 to +131	+5 to +105	(-)70	-26	354	56	-298	178	338	+160	9.0	10	+1.0
4	-65 to +131	+50 to +160	(-)115	+29	0	5.6	+5.6	19.4	0	-19.4	9.0	10	+1.0
5	-94 to +91	+12 to +127	(-)106	+36	375	50	-325	58	0	-58	9.0	10	+1.0
6	-65 to +131	+70 to +141	(-)135	+10	51	5.6	-45.4	19.4	0	-19.4	9.0	10	+1.0
7	-65 to +131	+5 to +105	(-)70	-26	354	56	-298	178	338	+160	9.0	10	+1.0
8	-65 to +106	+50 to +170	(-)115	+64	0	10.8	+10.8	36	10.8	-25.2	9.0	10	+1.0
9	+62 to +82	+20 to +126	-42	+44	0	5.5	+5.5	0	5.5	-5.5	0	10	+10
10	-65 to +131	+70 to +141	(-)135	+10	51	5.6	-45.4	19.4	0	-19.4	9.0	10	+1.0
11	-65 to +160	-50 to +180	(-)15	+20	0	66	+66	330	200	-130	9.0	10	+1.0
12	-65 to +160	-50 to +180	(-)15	+20	0	66	+66	330	200	-130	9.0	10	+1.0
13	-65 to +131	+5 to +105	(-)70	-26	354	56	-298	178	338	+160	9.0	10	+1.0
14	+58 to +78	+20 to +126	-38	+48	0	42.5	+42.5	0	42.5	+42.5	0	10	+10
15	-31 to +120	+12 to +127	(-)77	+7	51	5.6	-45.4	19.4	0	-19.4	9	10	+1.0
16	-65 to +131	+50 to +160	(-)115	+29	0	5.6	+5.6	19.4	0	-19.4	9	10	+1.0
17	-65 to +131	+50 to +160	(-)115	+29	0	5.6	+5.6	19.4	0	-19.4	9.0	10	+1.0
18	-31 to +120	+12 to +127	(-)77	+7	0	5.6	+5.6	19.4	0	-19.4	9.0	10	+1.0
19	-65 to +106	+50 to +170	(-)115	+64	0	10.8	+10.8	36	10.8	-25.2	9.0	10	+1.0
20	-94 to +91	+12 to +127	(-)106	+36	375	50	-325	58	0	-58	9.0	10	+1.0
21	+62 to +131	+20 to +126	-42	-5	2.4	5.5	+3.1	4.15	5.5	+1.35	1-2	10	+9 to +8
22	-94 to +91	+12 to +127	(-)106	+36	375	50	-325	58	0	-58	9.0	10	+1.0
23	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
24	-65 to +160	+5 to +105	(-)70	-55	526	105	-421	306	105	-201	9.0	10	+1.0
25	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0
26	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
27	-65 to +160	-60 to +80	(-)125	-80	940	0	-940	158	0	-158	9.0	1.0	-8
28	-65 to +131	+50 to +160	(-)115	+29	0	5.6	+5.6	19.4	0	-19.4	9.0	10	+1.0
29	+58 to +78	+20 to +126	-38	+48	0	5.5	+5.5	0	5.5	+5.5	0	10	+10
30	-65 to +131	+5 to +105	(-)70	-26	354	56	-298	178	338	+160	9.0	10	+1.0
31	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0
32	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
33	+62 to +131	+20 to +126	-42	-5	2.4	5.5	+3.1	4.15	5.5	+1.35	1-2	10	+9 to +8
34	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
35	-65 to +131	+50 to +160	(-)115	+29	0	175	+175	590	0	-590	9.0	10.0	+1.0
36	+62 to +131	+20 to +126	-42	-5	2.4	5.5	+3.1	4.15	5.5	+1.35	1-2	10	+9 to +8
37	-65 to +160	-60 to +80	(-)125	-80	940	0	-940	158	0	-158	9.0	1.0	-8.0

TABLE 4 AIR AMBIENT TEMPERATURE PARAMETERS (Continued)

WRA NO.	RANGE °F LAB	RANGE °F FIELD	Δ °F MIN	Δ °F MAX	DURATION-HI-TEMP. HRS. LAB	DURATION-HI-TEMP. HRS. FIELD	DURATION-HI-TEMP. Δ HRS.	DURATION-LO-TEMP. HRS. LAB	DURATION-LO-TEMP. HRS. FIELD	DURATION-LO-TEMP. Δ HRS.	RATE OF CHANGE °/MIN. LAB	RATE OF CHANGE °/MIN. FIELD	RATE OF CHANGE Δ °/MIN.
38	-65 to +160	+10 to +120	(-)75	-40	224	90	-134	555	270	-285	9.0	10	+1.0
39	-65 to +160	+10 to +120	(-)75	-40	224	90	-134	555	270	-285	9.0	10	+1.0
40	-65 to +160	+10 to +120	(-)75	-40	224	90	-134	555	270	-285	9.0	10	+1.0
41	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
42	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
43	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
44	-94 to +91	-48 to +160	(-)46	+69	0	50	+50	58	25	-33	9	10	+1.0
45	+58 to +78	+20 to +126	-38	+48	0	42.5	+42.5	0	42.5	+42.5	0	10	+10
46	-65 to +160	+10 to +120	(-)75	-40	890	75	-815	324	226	-98	9.0	10	+1
47	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
48	-65 to +160	+10 to +120	(-)75	-40	1450	115	-1335	730	350	-380	9.0	10	+1
49	+58 to +78	+20 to +126	-38	+48	0	42.5	+42.5	0	42.5	+42.5	0	10	+10
50	-65 to +131	+50 to +160	(-)115	+29	0	5.6	+5.6	19.4	0	-19.4	9	10	+1.0
51	+10 to +131	+20 to +126	+10	-5	570	85	-485	680	85	-595	1-4	10	+9 to +6
52	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
53	-65 to +160	+30 to +120	(-)95	-40	224	90	-134	555	270	-285	9.0	1.0	-8.0
54	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0
55	-65 to +160	-60 to +80	(-)125	-80	940	0	-940	158	0	-158	9.0	1.0	-8.0
56	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0
57	-65 to +160	+30 to +120	(-)95	-40	224	90	-134	555	270	-285	9.0	1.0	-8.0
58	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0
59	-65 to +160	+60 to +80	(-)125	-80	580	0	-580	88	0	-88	9.6	1.0	-8.6
60	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9	10	+1.0
61	-65 to +160	+30 to +120	(-)95	-40	1450	115	-1335	730	350	-380	9.0	1.0	-8.0
62	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0
63	+62 to +131	+20 to +126	-42	-5	2.4	5.5	+3.1	4.15	5.5	+1.35	1-2	10	+9 to +8
64	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9	10	+1.0
65	-65 to +160	+30 to +120	(-)95	-40	1450	115	-1335	730	350	-380	9.0	1.0	-8.0
66	-94 to +91	+60 to +80	(-)154	-11	375	0	-375	58	0	-58	9.0	10	+1.0
67	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0
68	-65 to +131	+60 to +80	(-)125	-51	354	0	-354	178	0	-178	9.0	1.0	-8.0
69	+62 to +131	+20 to +126	-42	-5	2.4	5.5	+3.1	4.15	5.5	+1.35	1-2	10	+9 to +8
70	-31 to +120	+50 to +160	(-)81	+40	51	0	-51	19.4	0	-19.4	9	10	+1.0
71	-65 to +160	+30 to +120	(-)95	-40	600	66	-534	450	200	-250	9.0	1.0	-8.0
72	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0
73	-65 to +131	+60 to +80	(-)125	-51	354	0	-354	178	0	-178	9.0	1.0	-8.0
74	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0

TABLE 4 AIR AMBIENT TEMPERATURE PARAMETERS (Continued)

WRA NO.	RANGE °F		RANGE Δ °F		DURATION-HI-TEMP. HRS.		DURATION-HI-TEMP. Δ	DURATION-LO-TEMP. HRS.		DURATION-LO-TEMP. Δ	RATE OF CHANGE °/MIN.		RATE OF CHANGE Δ
	LAB	FIELD	MIN	MAX	LAB	FIELD	HRS.	LAB	FIELD	HRS.	LAB	FIELD	°/MIN.
75	-65 to +131	+60 to +80	(-)125	-51	354	0	-354	178	0	-178	9.0	1.0	+1.0
76	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
77	-31 to +120	+60 to +80	(-)91	-40	51	0	-51	19.4	0	-19.4	9.0	10	+1.0
78	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
79	-65 to +131	+50 to +160	(-)115	+29	0	5.6	+5.6	19.4	0	-19.4	9	10	+1.0
80	-65 to +160	+10 to +120	(-)75	-40	0	66	+66	330 ≤ 50	200 ≤ 50	-130	9.0	10	+1.0
81	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
82	-65 to +131	+5 to +105	(-)70	-26	354	56	-298	178	338	+160	9.0	10	+1.0
83	-65 to +131	+12 to +127	(-)77	-4	51	5.6	-45.4	19.4	0	-19.4	9.0	10	+1.0
84	+62 to +82	+20 to +126	-42	+44	0	5.5	+5.5	0	5.5	+5.5	0	10	+10
85	-94 to +91	+12 to +127	(-)106	+36	375	25	-350	58	0	-58	9	10	+1.0
86	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
87	-65 to +160	+10 to +120	(-)75	-40	224	90	-134	555	270	-285	9.0	10	+1.0
88	-65 to +160	+10 to +120	(-)75	-40	224	90	-134	555	270	-285	9.0	10	+1.0
89	-65 to +160	+10 to +120	(-)75	-40	224	90	-134	555	270	-285	9.0	10	+1.0
90	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0
91	-65 to +160	+10 to +120	(-)75	-40	224	90	-134	555	270	-285	9.0	10	+1.0
92	+62 to +131	+20 to +126	-42	-5	2.4	5.5	+3.1	4.15	5.5	+1.35	1-2	10	+9 to +8
93	+59 to +77	+20 to +126	-39	+40	0	41	+41	0	41	+41	0	1.0	+1.0
94	+62 to +131	+20 to +126	-42	-5	2.4	5.5	+3.1	4.15	5.5	+1.35	1-2	10	+9 to +8
95	+59 to +77	+20 to +126	-39	+49	0	41	+41	0	41	+41	0	1.0	+1.0

TABLE 5 EQUIPMENT COOLING AIR PARAMETERS

WRA NO.	TEMPERATURE RANGE °F		Δ - °F		TEMP. - RATE OF CHANGE °/MIN		Δ	FLOW - RATE OF CHANGE #/MIN/MIN		Δ	FLOW - RANGE #/MIN		Δ - #/MIN		DURATION HOURS		Δ
	LAB	FIELD	MIN	MAX	LAB	FIELD	°/MIN	LAB	FIELD	#/MIN/MIN	LAB	FIELD	MIN	MAX	LAB	FIELD	HRS
1	+70 to +80	+70 to +80	0	0	0	0	0	0	0	0	0.60	0.61	-	+0.01	85	113	+28
2	+93 CONST	+3 to +166	-90	+73	0	0	0	0	0	0	5	3.27 to 20.25	-1.73	+15.25	162	21	-141
4	+70 to +80	+70 to +80	0	0	0	0	0	0	0	0	0.60	0.66	-	+0.06	85	113	+28
6	0 to +80	+70 to +80	0	0	0	0	0	0	0	0	0.55	0.55	-	0	85	113	+28
7	+75 to +85	+60 to +80	-15	-5	INSTAN.	1.0	> -1	0.60	0.60	0	1.8 to 2.2	1.1 to 2.2	-0.7	0	382	85	-297
8	+93 CONST	+3 to +166	-90	+73	0	0	0	0	0	0	5	3.27 to 20.25	-1.73	+15.25	162	21	-141
9	+35 to +115	+60 to +70	+25	-45	NEGLIG.	NEGLIG.	0	NEGLIG.	NEGLIG.	0	0.68	0.68	0	0	111	111	0
10	+70 to +80	+70 to +80	0	0	0	0	0	0	0	0	0.55	0.55	-	0	85	113	+28
13	+75 to +85	+60 to +80	-15	-5	INSTAN.	1.0	> -1	0	0.05	+0.05	0.28 to 0.34	0.16 to 0.30	-0.12	-0.04	382	85	-297
14	+70 to +115	+60 to +70	-10	-45	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	1.16 to 1.4	0.52	-0.64	-0.88	850	850	0
17	+70 to +80	+70 to +80	0	0	0	0	0	0	0	0	0.36	0.59	-	+0.23	85	113	+28
19	+93 CONST.	+3 to +166	-90	+73	0	0	0	0	0	0	5	3.27 to 20.25	-1.73	+15.25	162	21	-141
23	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
24	+35 to +120	+40 to +60	+5	-60	INSTAN.	10	> -10	0.26	0.26	0	0.4 to 1.2	1.10 to 1.45	+0.70	+0.25	485	63	-422
26	+11 to +70	+60 to +70	-49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
27	-65 to +120	+40 to +60	(-)105	-60	2.0	10	+8	0.12	0.12	0	0.3 to 1.2	0.53 to 0.72	+0.23	-0.48	880	285	-595
28	+70 to +80	+70 to +80	0	0	0	0	0	0	0	0	0.89	0.89	0	0	85	113	+28
29	+35 to +115	+60 to +70	+25	-45	NEGLIG.	NEGLIG.	0	NEGLIG.	NEGLIG.	0	6.4	6.4	0	0	111	111	0
30	+75 to +85	+60 to +80	15	-5	INSTAN.	1.0	> -1	0.10	0.10	0	0.135 to 0.165	0.13 to 0.32	-0.005	+0.155	382	163	-219
33	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
34	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
37	-65 to +120	+40 to +60	(-)105	-60	2.0	10	+8	0.30	0.30	0	0.6 to 2.4	1.35 to 1.85	+0.75	-0.55	880	285	-595
41	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
42	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
43	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
45	+70 to +115	+60 to +70	-10	-45	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	1.16 to 1.4	0.52	-0.64	-0.88	850	850	0
46	+80	+59 to +65	-21	-15	NEGLIG.	NEGLIG.	0	NEGLIG.	NEGLIG.	0	0.65	0.52 to 0.598	-.13	-0.06	1130	1512	+382
47	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0

TABLE 5 EQUIPMENT COOLING AIR PARAMETERS (Continued)

WRA NO.	TEMPERATURE RANGE °F		Δ - °F		TEMP. - RATE OF CHANGE °/MIN		Δ	FLOW - RATE OF CHANGE #/MIN/MIN		Δ	FLOW - RANGE #/MIN		Δ - #/MIN		DURATION HOURS		Δ
	LAB	FIELD	MIN	MAX	LAB	FIELD	°/MIN	LAB	FIELD	#/MIN/MIN	LAB	FIELD	MIN	MAX	LAB	FIELD	HRS
48	+80	+59 to +65	-21	-15	NEGLIG.	NEGLIG.	0	NEGLIG.	NEGLIG.	0	0.61	0.51 to 0.596	-.10	-0.03	1620	2330	+710
49	+70 to +115	+60 to +70	-10	-45	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	1.16 to 1.4	0.61	-0.55	-0.79	850	850	0
50	+70 to +80	+70 to +80	0	0	0	0	0	0	0	0	1.20	1.20	0	0	85	113	+28
52	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
76	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
78	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
79	+70 to +80	+70 to +80	0	0	0	0	0	0	0	0	1.50	2.80	-	-1.30	85	113	+28
81	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
82	+75 to +85	+60 to +80	-15	-5	INSTAN.	1.0	> 1	0.25	0.25	0	0.81 to 0.99	0.46 to 0.89	-0.35	-0.10	382	85	-297
83	+70 to +80	+70 to +80	0	0	0	0	0	0	0	0	1.00	1.00	0	0	85	113	+28
84	+35 to +115	+60 to +70	+25	-45	NEGLIG.	NEGLIG.	0	NEGLIG.	NEGLIG.	0	3.76	3.76	0	0	111	111	0
86	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
90	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to -7.5	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
93	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to **-7.5**	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0
95	+11 to +70	+60 to +70	+49	0	0.72 to 7.5	0	-0.72 to **-7.5**	NEGLIG.	NEGLIG.	0	13 to 14	19.78	+6.78	+5.78	831	831	0

described above and represent the extreme conditions based on cold day/coldest mission and hot day/hottest mission. The indicated duration at temperature extremes were referenced to laboratory test time and were calculated by defining the percentage of time the aircraft remained at similar extremes (for a composite mission) and multiplying this percentage by total test operating hours. The values so obtained could then be compared directly with lab test durations under similar conditions. Rates of change listed for each item are the maximums encountered in flight. The delta columns represent the difference between lab and field and the rule established was "field minus lab." Hence, a positive sign denotes that the field value was greater and a negative sign indicates a lower field condition. For temperature differences a negative sign was bracketed to avoid confusion with sub-zero temperaturees. Except for rate of ambient temperature change, field conditions were generally more benign than laboratory exposure.

3.2.2 Moisture

Moisture as defined for this study is a somewhat all inclusive term encompassing humidity, precipitation, condensation, salt fog, icing, etc. Although all forms of moisture are present and may affect equipment performance, it is the absolute humidity (mass of water vapor per unit volume of space) manifested as condensation and precipitation which most seriously affect electronic equipment. For example, for icing to occur requires an unusual set of circumstances:

- Soak of aircraft at low temperature (due to high altitude flight) and then a descent at some optimum rate to drop surface temperature below dewpoint, or
- Flight of aircraft through a supercooled cloud which upsets the equilibrium of the unstable air mass causing freezing of water droplets.

Even if icing did occur, it is limited to external aircraft surfaces and does not appear on internal avionic equipment. More serious forms of moisture exposure may occur in three basic areas:

- Prolonged exposure to high ambient humidity (on the ground) manifested as free moisture:
  - Carrier operation which would include a certain salt content and result from spray.
  - Night temperature dropping below the dewpoint causing precipitation.
- Freezing of entrapped moisture at a certain altitude.
- Condensation, again due to altitude (hence temperature) variations, within forced air cooled boxes.

In forced air cooled boxes any free moisture which may be present would probably tend to degrade electronic equipment performance. However, if the equipment were cold plate cooled, air would not impinge on the components and moisture would actually provide additional cooling represented by the latent heat of the water. Current design practice is to avoid the forced air cooled construction wherein air flows directly over parts, instead the use of indirect cooling techniques such as the cold plate are generally employed. Many laboratory demonstration requirements dictate that extreme precautions be taken so that humidity effects do not adversely affect equipment performance. It is estimated that the relative humidity maintained during a typical test is less than 10%. While it is difficult to quantify moisture due to field operation, certain facts are known. The world average is 75% and the aircraft in this study are exposed to at least this condition for a good percentage of their life. In addition, carrier operations add considerable free moisture including a certain salt content. During the remainder of the study period moisture effects will be further evaluated and a specific recommendation made at that time.

3.2.3 Vibration

The field vibration environment was examined for those aircraft locations which embodied the selected study equipment.

Instrumentation

Vibration measurements were acquired utilizing an Endevco piezoelectric crystal accelerometer which combines high sensitivity, broad temperature range, high resonant frequency and high capacitance into a lightweight, reliable sensor. At each measurement location a tri-axial cluster of accelerometers was installed, such that the minimum resonant frequency of the installation was greater than 600 Hz. In all the measurement programs conducted, a sixteen track hybrid tape recorder capable of recording 4 tracks of proportional bandwidth analog data was utilized.

Data Acquisition

The vibration information obtained was reduced on a Federal Scientific (Ubiquitous) Real Time Power Spectral Density System. This system is comprised of a highly advanced group of equipment for analyzing sinusoidal, transient, random, or pseudo random signals in the shortest time possible.

Since there are two (2) types of engine configuration evaluated in this report, the data sample length varied.

- In the case where the engine is a PROP-JET and rotates at constant speed (1106 RPM), the environment is predominantly sinusoidal. It is then possible to acquire 10 to 15 second time samples and spectrum analyze the data with a 1.6 Hz. bandwidth filter to obtain a good confidence level. The vibration levels are presented as peak g.
- The TURBO JET engine power plants primarily exhibit insignificantly low level broad band random base, and more prevalent narrow band spikes representing predominant structural modes and engine rotational speeds for the various flight conditions Therefore, utilizing the 3.3 Hz. bandwidth filter associated with the ubiquitous analyzer, a sample length of approximately 20 seconds is required to obtain the required 128 degrees of freedom for good statistical quality, e.g.,

$K = 2 \cdot f \cdot t$ — K = degrees of freedom

$K = (2)\ (3.3)\ (20)$ — f = filter bandwidth

$K = 132$ degrees of freedom — t = data sample (in seconds)

Flight Conditions

The information employed for this report was gathered from other programs for substantiation of reduction in the vibration qualification levels for the most severe conditions. Therefore, the flight conditions that produce the most severe vibration environment are: 1) maximum power on the ground and 2) maximum speed near sea level (5000 ft.).

The actual environmental effect on the equipment is also a function of its location and installation details in the aircraft. Thus, a complete investigation for each equipment in question was necessary in order to determine the most severe condition. Additionally, if there was any doubt, both conditions were measured.

Analysis

Since vibration data is best expressed in the form of Power Spectral Density (PSD) plots (as opposed to a tabulation) the information obtained is presented graphically for locations which best described the vibration environments for each selected equipment. Further, since the vibration effect on an equipment is a function of both aircraft structure and the propulsion system, the PSD plots are presented for each equipment in terms of its particular aircraft/location/engine combinations. The flight conditions shown include; cruise, intermediate (INTERM) and maximum after burner (MAX A/B)

1. Prop-Jet - The engine power source for the Prop-Jet consiste of two turbo-jet constant speed engines with four (4) bladed propellers. Figures 9, 10 and 11 are acceleration vs. frequency data plots for the equipments affected by this aircraft/engine combination.
   - Figure 9 is the plot for WRA's 9, 21, 29, 36, 51, 63, 69, 84, 92 and 94.
   - Figure 10 is the plot for WRA's 12, 23, 26, 32, 34, 41, 42, 43, 45, 47, 49, 52, 76, 78, 81, 86, 90, 93 and 95.
   - Figure 11 is the plot for WRA No. 33.

The F.S. No. in the figures is the fuselage station in inches from nose.

The vibration levels presented in the above figures are plotted in acceleration ("g" vector) due to the periodic content in the significant data gathered. The predominant frequency is 73.0 Hz. (propeller blade passage (4P)) and the levels were recorded during both high speed cruise and ground engine run flight conditions.

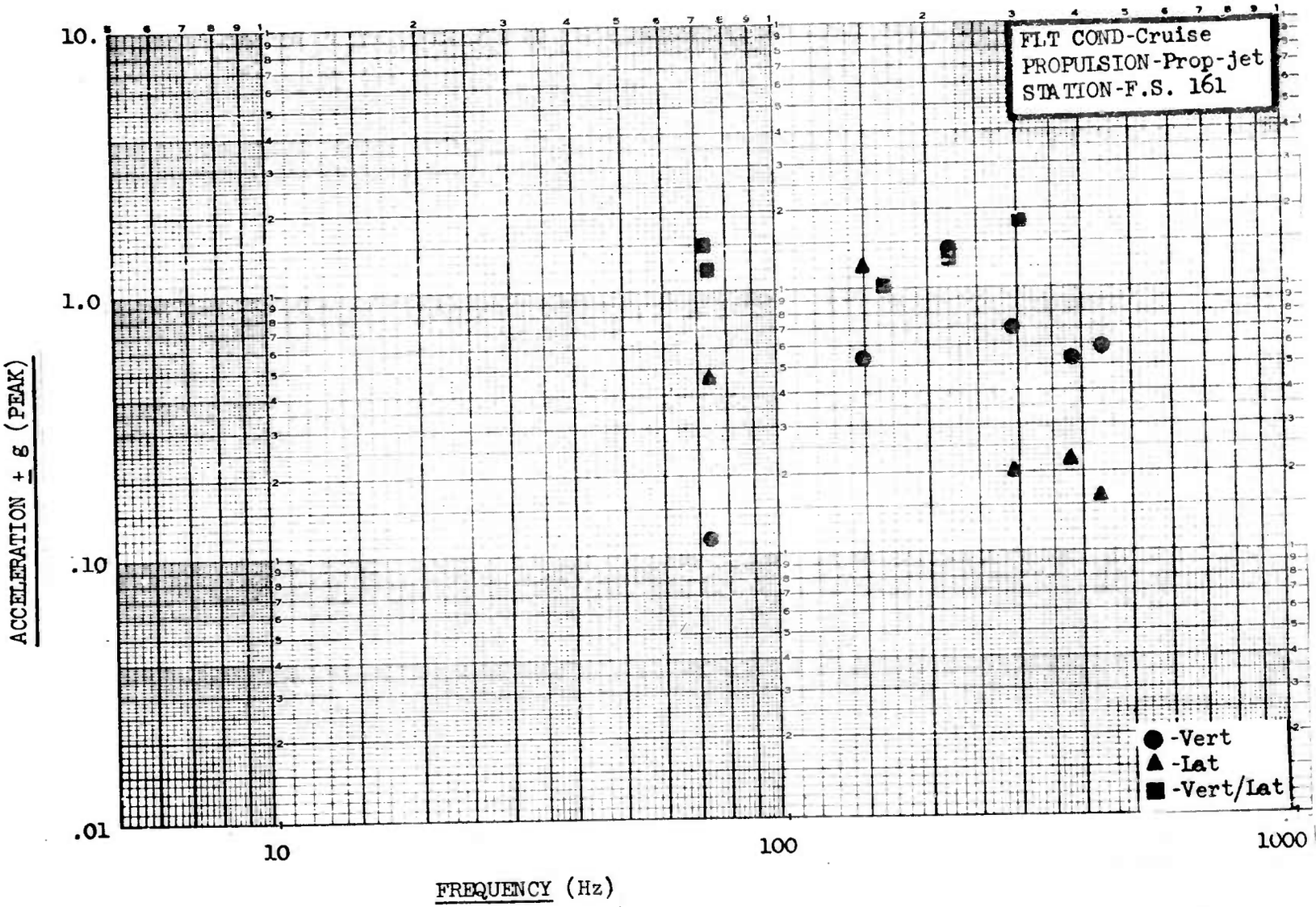


FIGURE 9 ACCELERATION VS. FREQUENCY PLOT FOR PROP JET - CASE 1

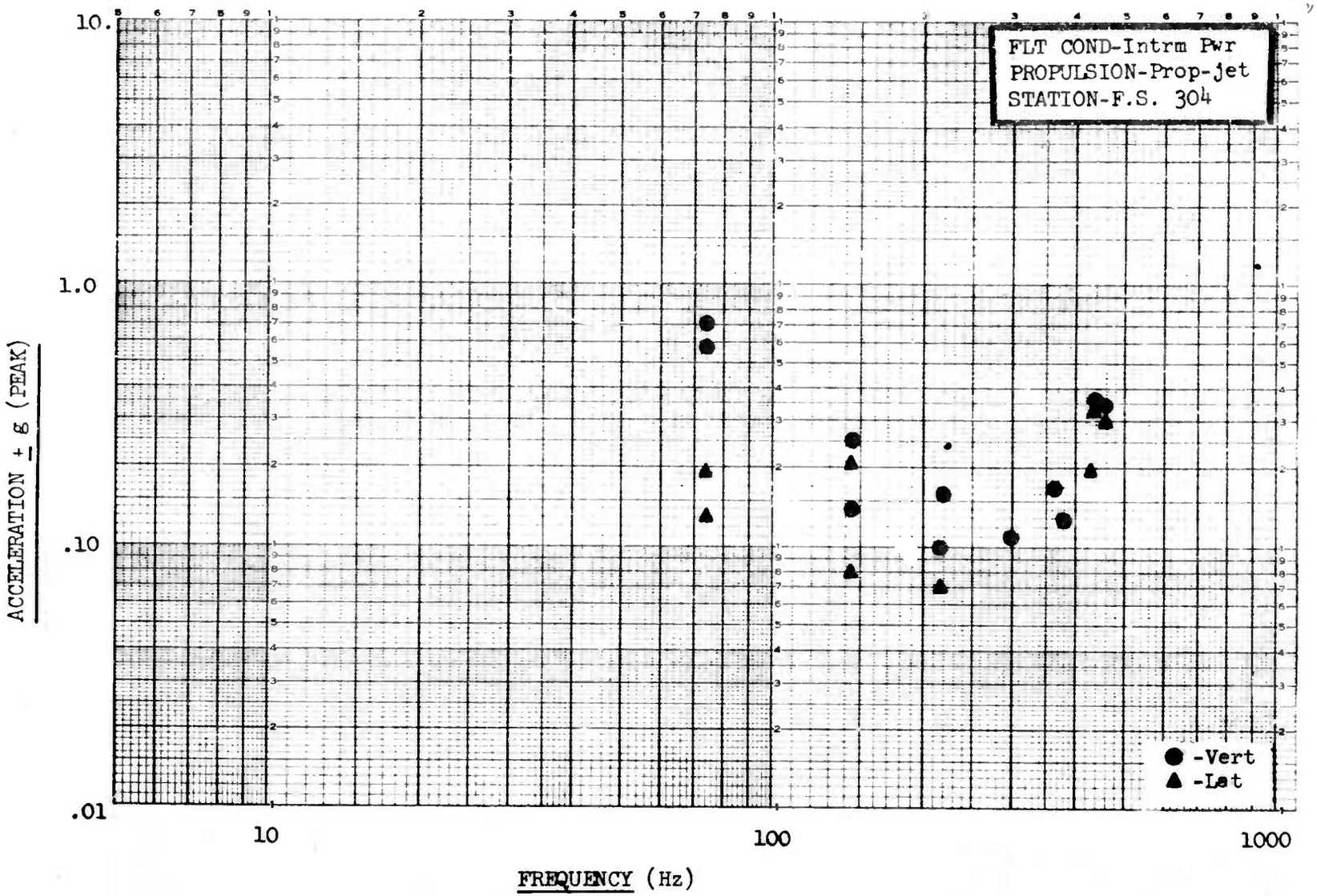


FIGURE 10 ACCELERATION VS. FREQUENCY PLOT FOR PROP JET - CASE 2

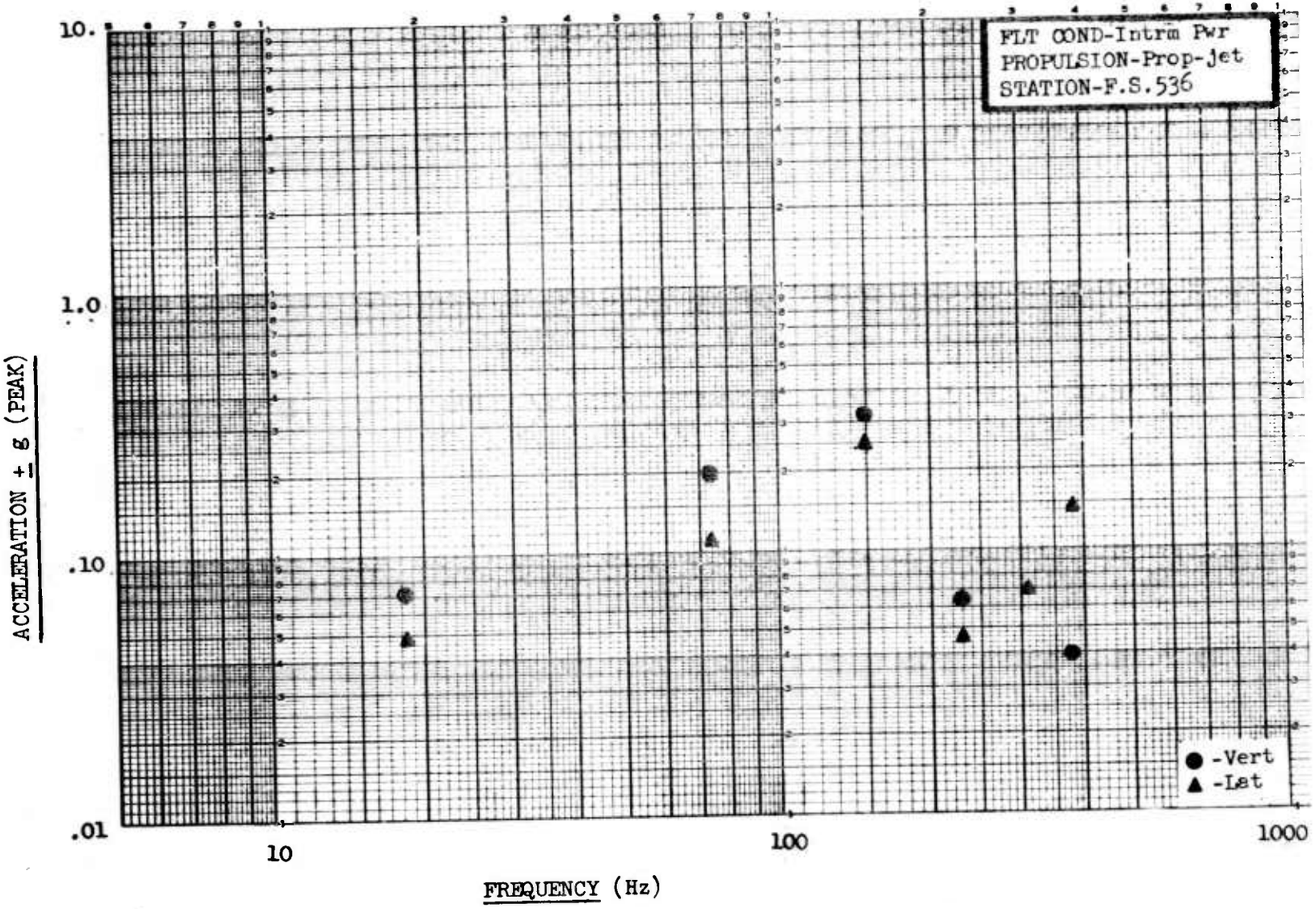


FIGURE 11 ACCELERATION VS. FREQUENCY PLOT FOR PROP JET - CASE 3

A review of the vibration measurements recorded throughout the fuselage clearly defines the predominant frequency content to be sinusoidal and directly associated with the engine propeller shaft speed (18.4 Hz.), propeller blade passage frequency (73.2 Hz.) and their harmonics. The maximum "g" responses appear at 73.4 Hz. and 146.8 Hz. Additionally, the vibration levels vary in magnitude as measurements are taken fore and aft of the propeller plane, the most severe being at the propeller.

2. Turbo-Jet #1 - The aircraft is powered by two turbo-jet engines mounted approximately mid-fuselage. The engine exhaust, inpinging on the fuselage, produces relatively severe vibration levels in the aft fuselage. Utilizing the 3.3 Hz. bandwidth filters, the data disclosed narrow band random peaks at structural modes (e.g., fuselage vertical bending and torsion) and engine rotation speeds superimposed on a low level broad band random base.

Figures 12 through 19 are PSD plots for the equipment affected by this aircraft/engine combination. The F.S. No. in the figures is the fuselage station in inches from the aircraft nose.

- Figure 12 is the PSD for WRA's 54, 56, 58, 60, 62, 67, 70, 72, 74, 77 and 83.
- Figure 13 is the PSD for WRA's 54, 56, 58, 60, 62, 67, 70, 72, 74, 77 and 83.
- Figure 14 is the PSD for WRA's 15, 16, 20, 25, 31, 54, 60, 64, 67, 72, 74 and 77.
- Figure 15 is the PSD for WRA's 5, 22 and 44.
- Figure 16 is the PSD for WRA's 2, 8 and 19.
- Figure 17 is the PSD for WRA's 1, 4, 17, 28, 50, 66 and 79.
- Figure 18 is the PSD for WRA's 1, 4, 17, 28, 50 and 79.
- Figure 19 is the PSD for WRA's 6, 10 and 18.

The vibration levels reflect considerable variation in level across the fuselage due to the engine location. The environment is described as a low level broad band random with narrow band spikes due to various engine rotational speeds, structural modes (e.g., fuselage vertical bending and torsion), and major accessory drive mechanisms.

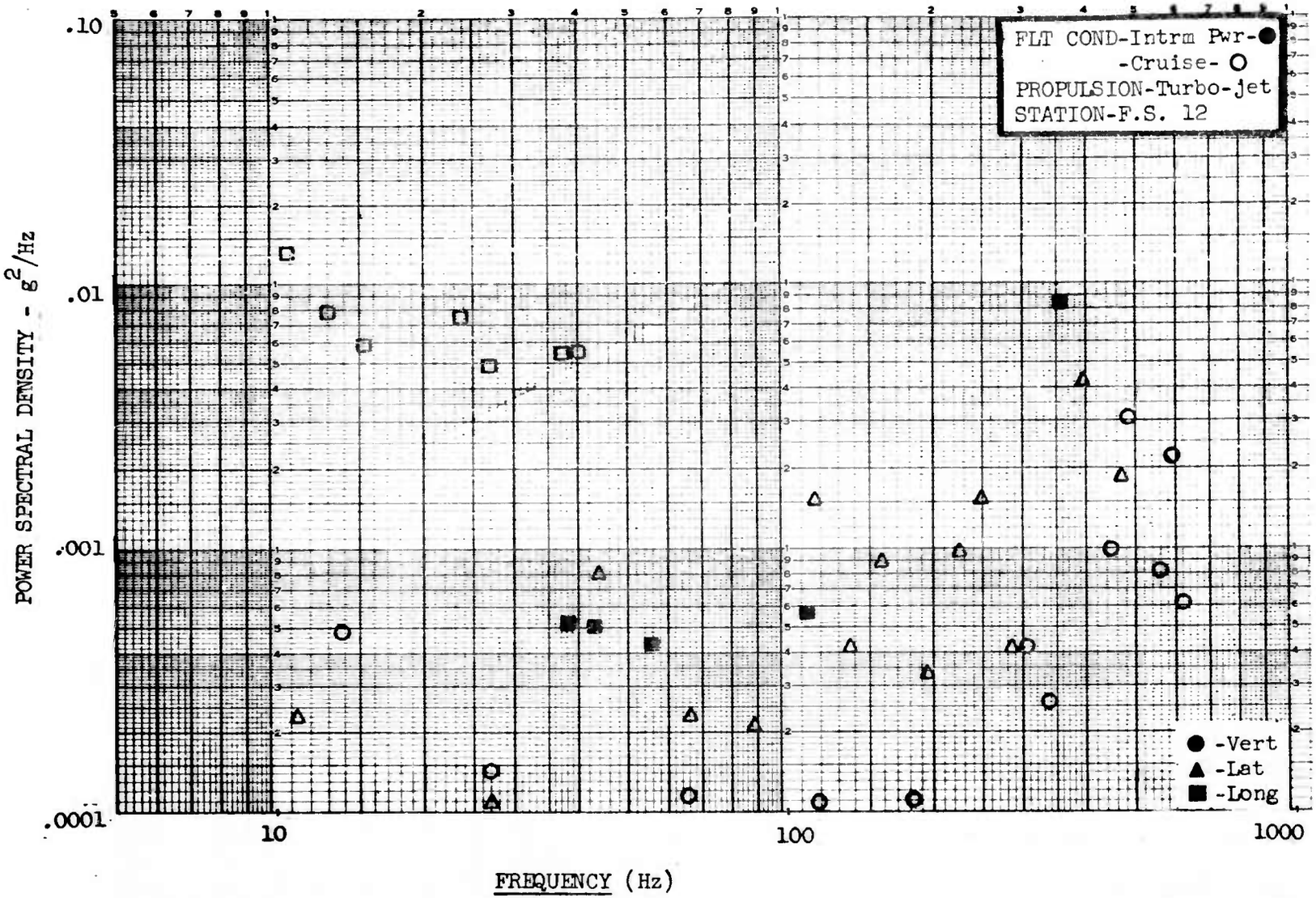


FIGURE 12 PSD PLOT CURVE FOR TURBO JET NO. 1 - CASE 1

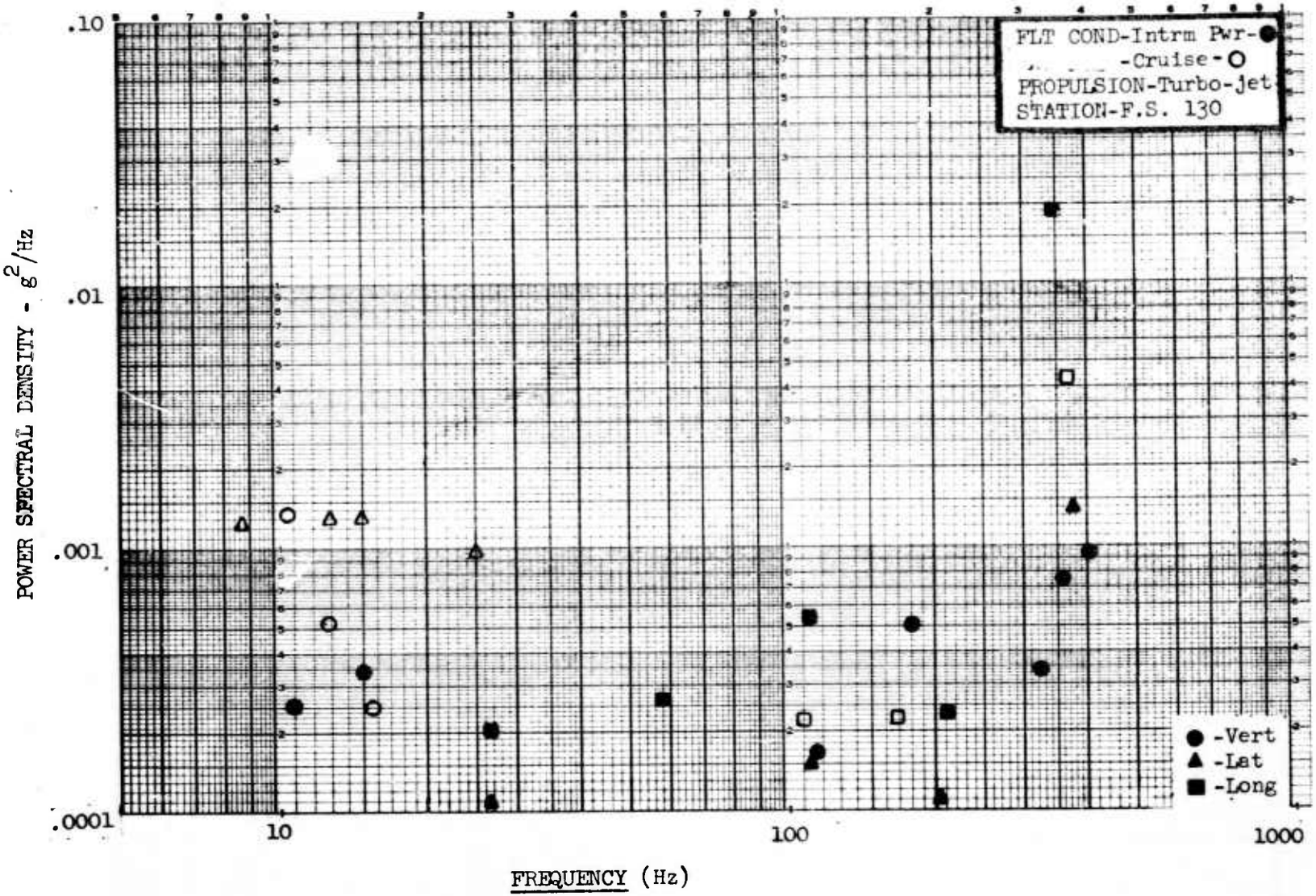


FIGURE 13 PSD PLOT FOR TURBO JET NO. 1 - CASE 2

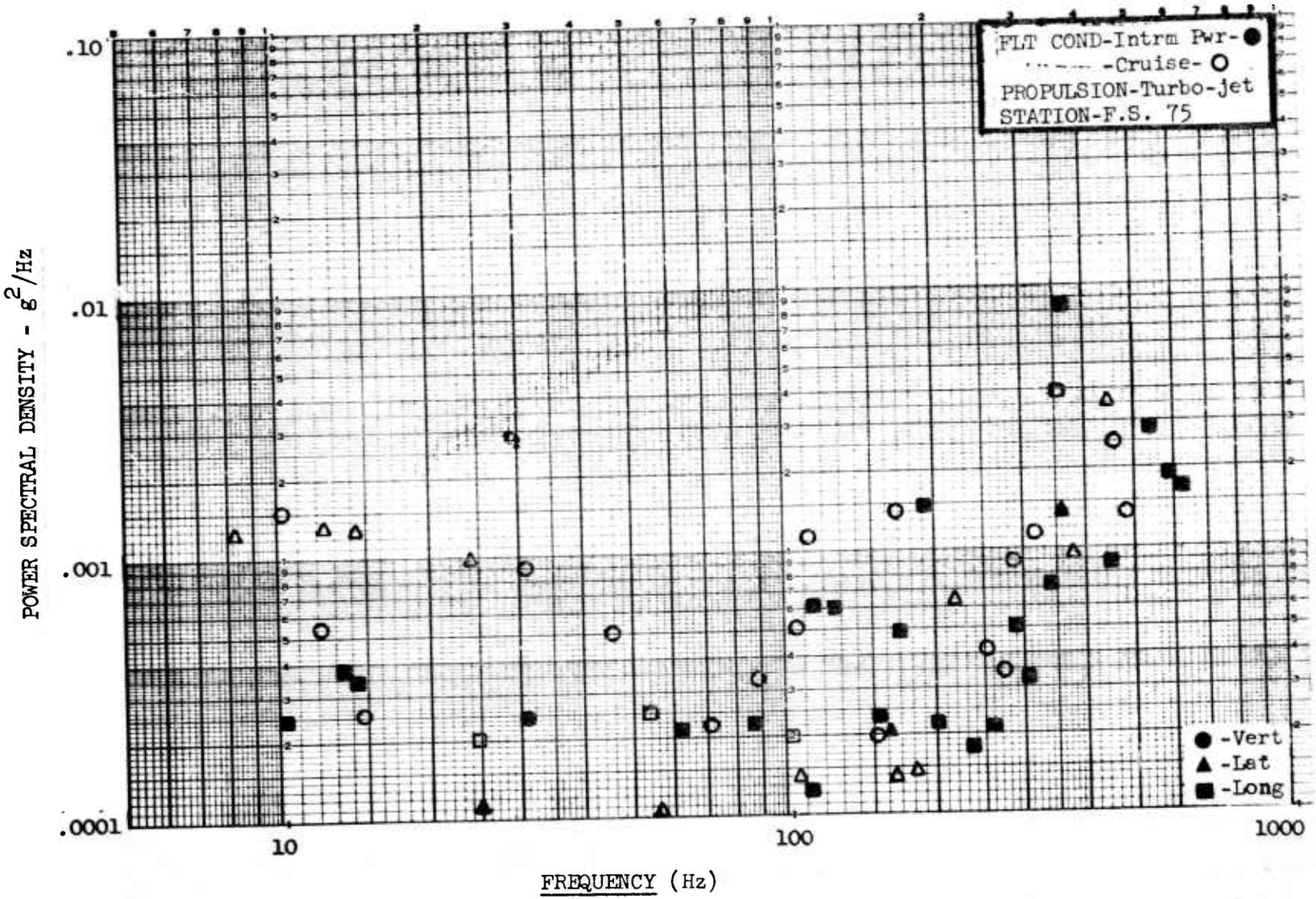


FIGURE 14 PSD PLOT FOR TURBO JET NO. 1 - CASE 3

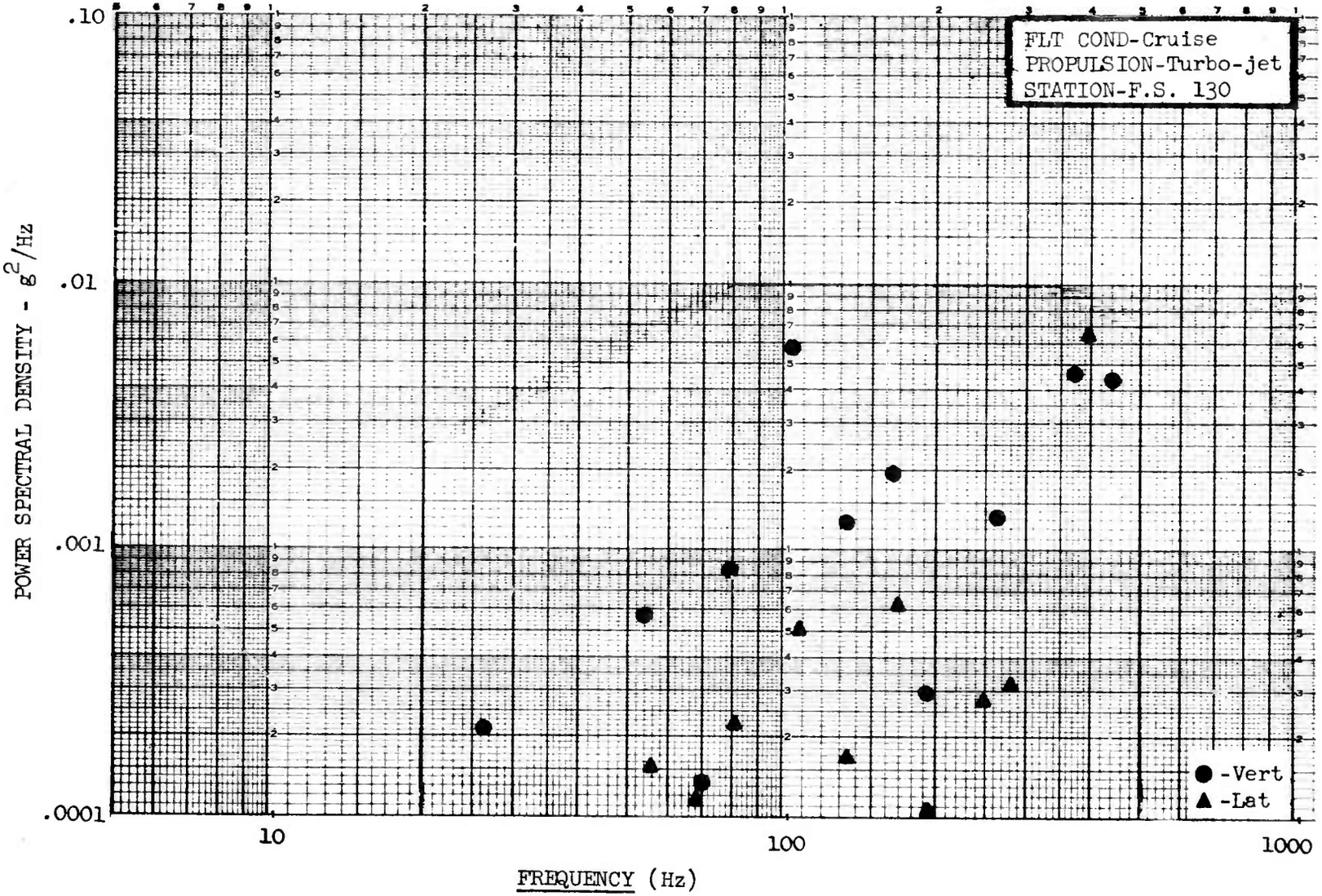


FIGURE 15 PSD PLOT FOR TURBO JET NO. 1 - CASE 4

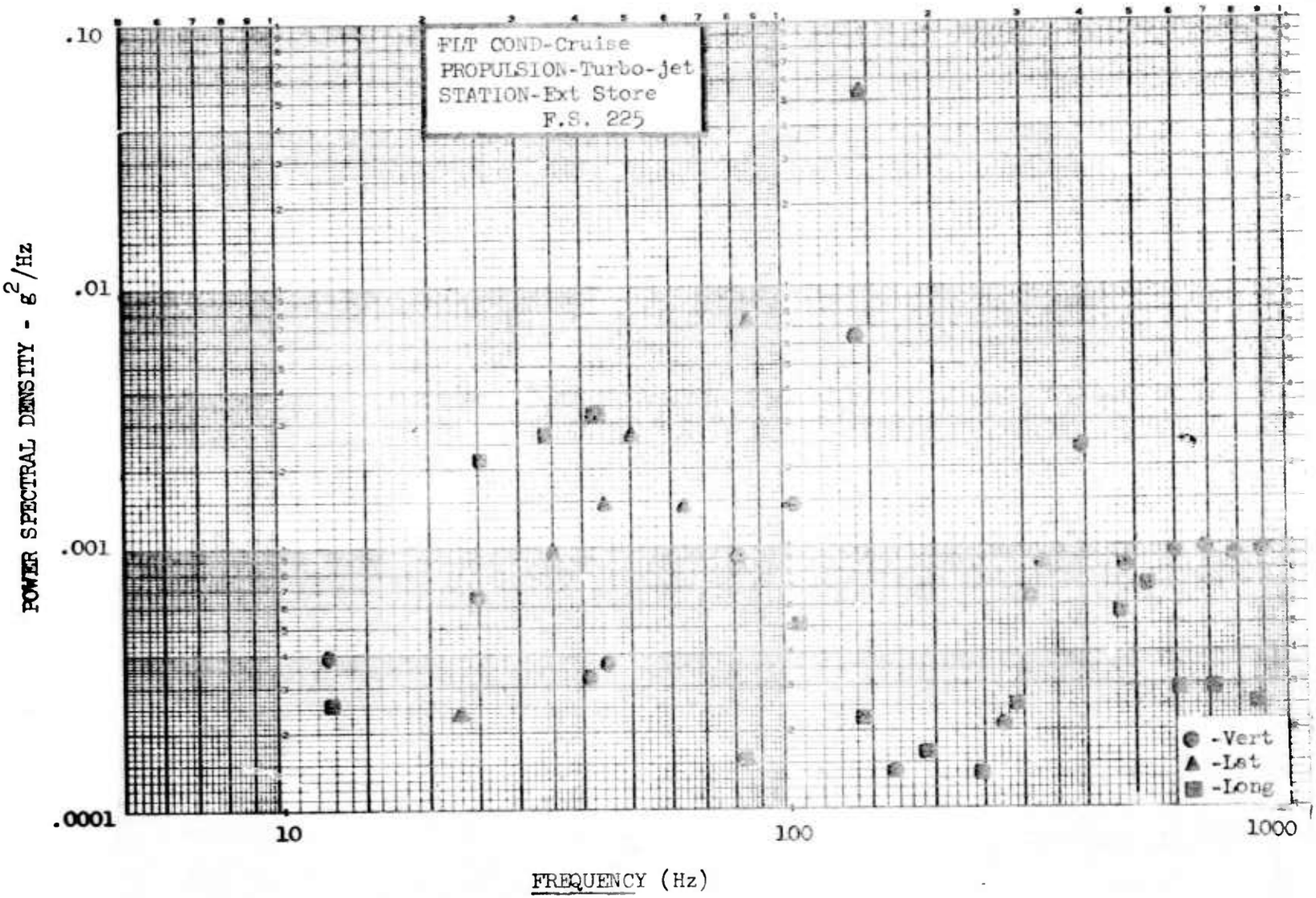


FIGURE 16 PSD PLOT FOR TURBO JET NO. 1 - CASE 5

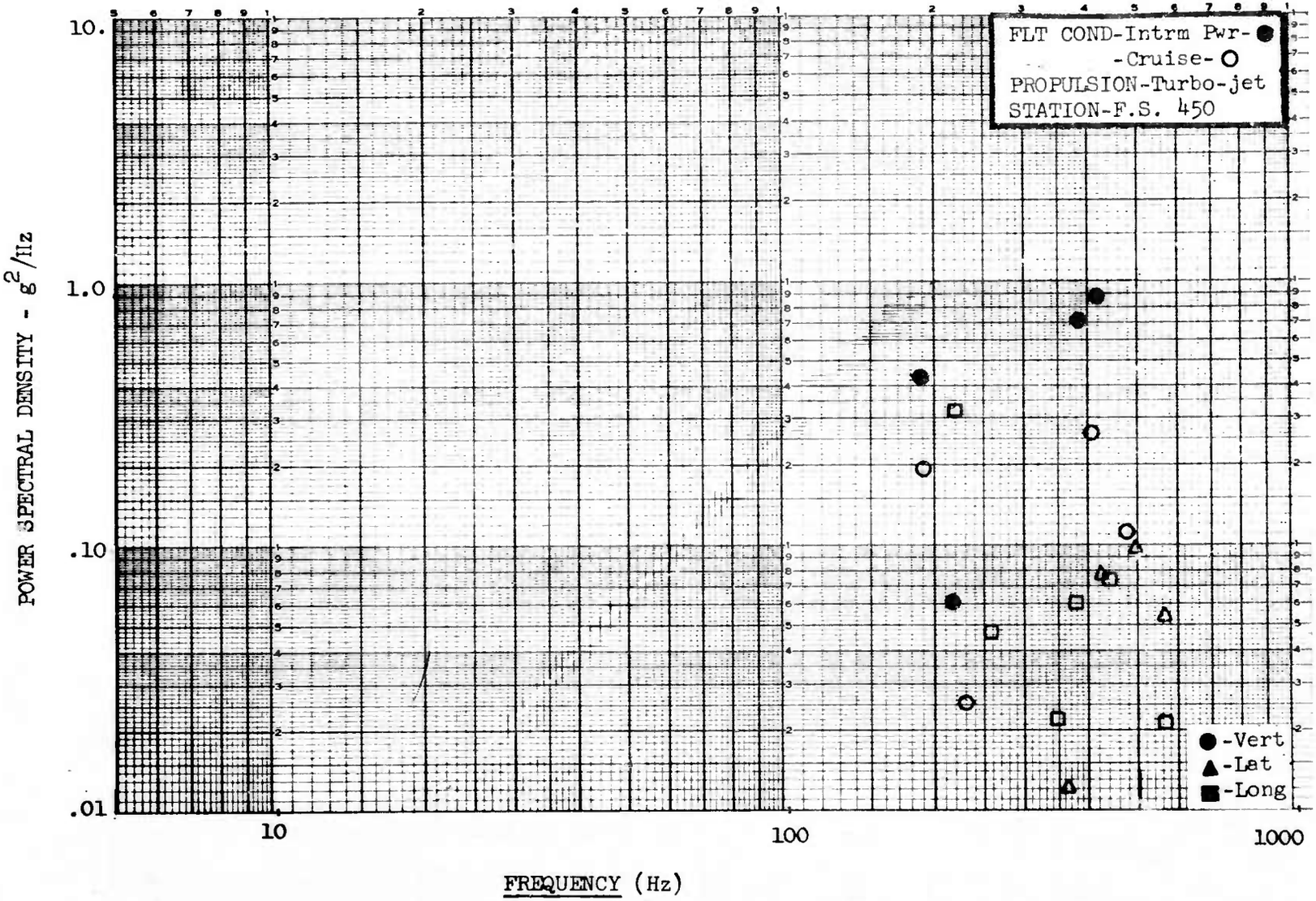


FIGURE 17 PSD PLOT FOR TURBO JET NO. 1 - CASE 6

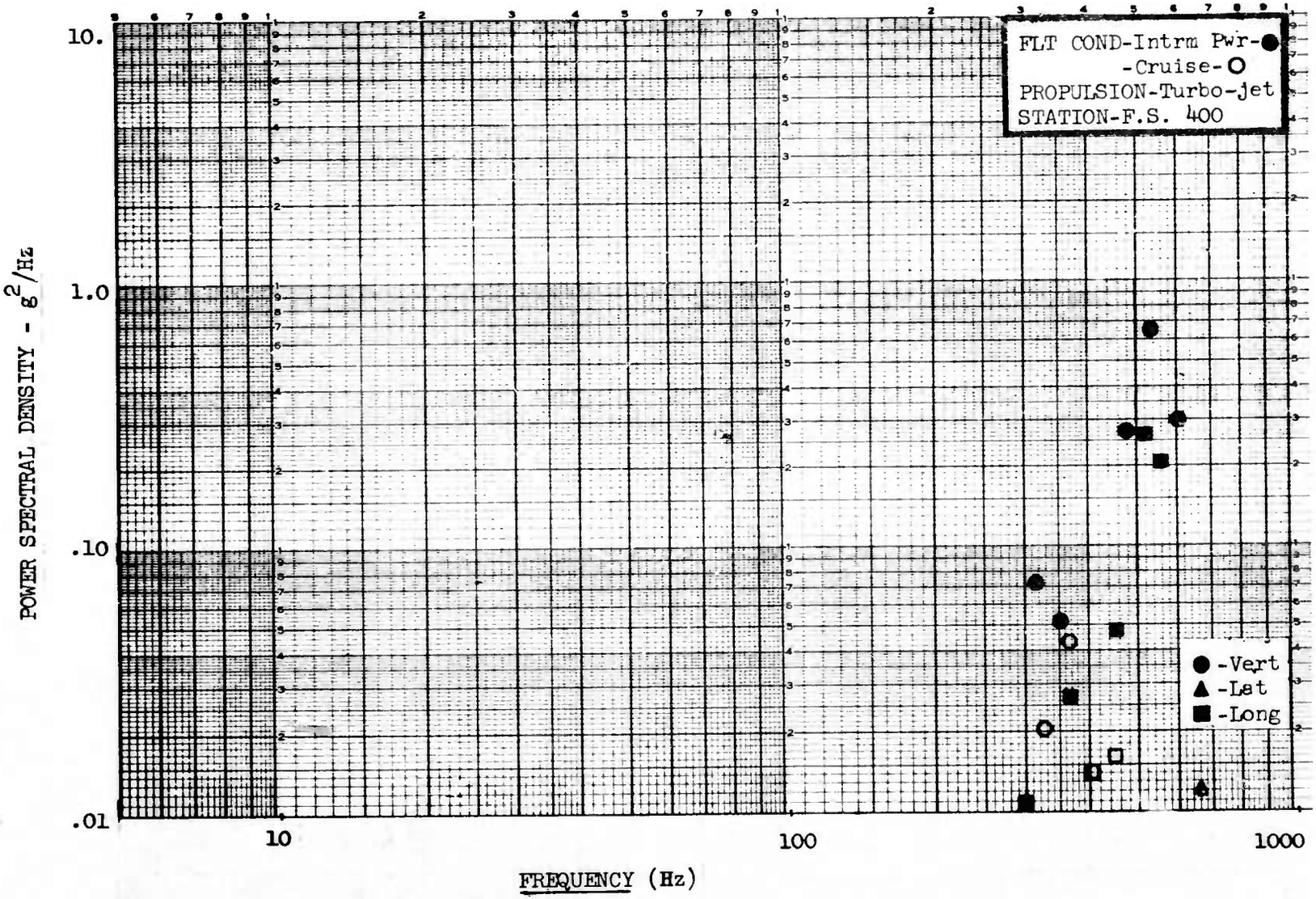


FIGURE 18 PSD PLOT FOR TURBO JET NO. 1 - CASE 7

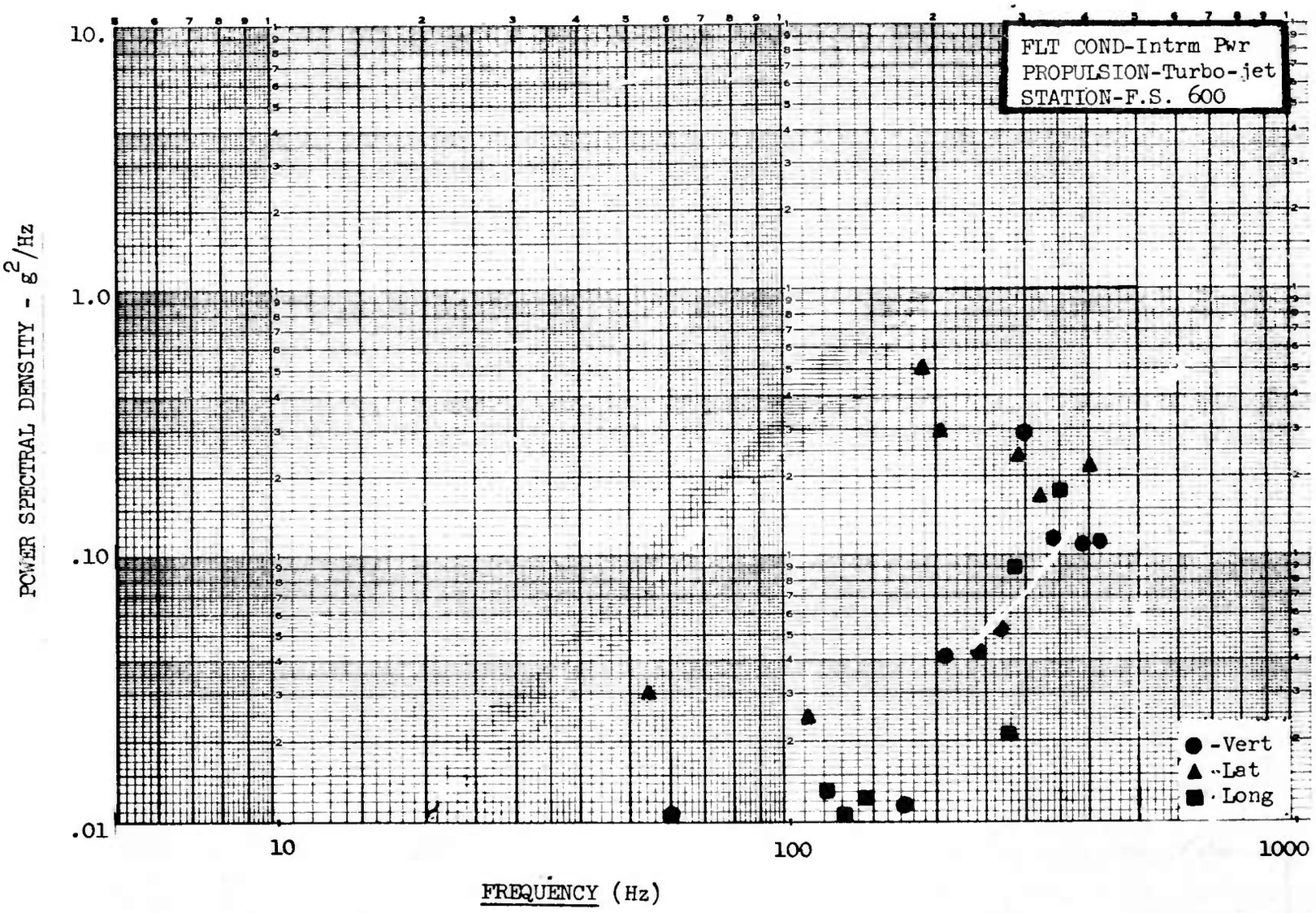


FIGURE 19 PSD PLOT FOR TURBO JET NO. 1 - CASE 8

3. Turbo-Jet #2 - This aircraft is powered by two turbo-jet engines located at the mid-fuselage, however, since the equipment of interest for this study is forward of the engines, vibration magnitudes are of a low magnitude random level. Figures 20 and 21 are PSD plots for the equipment affected by this aircraft/engine combination.

- Figure 20 is the PSD for WRA No. 3
- Figure 21 is the PSD for WRA's 3, 7, 13, 24, 27, 30, 37, 55, 59, 68, 73, 75, 82.

This environment is primarily low level broad brand random with narrow band spikes associated with engine operational rotational speeds, structural modes and other major accessory drive systems.

4. Turbo-Jet #3 - The main power source for this aircraft is two turbo-jet engines with afterburner, mounted in the aft fuselage, having no fuselage exhaust impingement. The vibration environment is primarily narrow band random (peaks associated with engine rotational speeds and structural modes) with the engine rotational vibration effects becoming less pronounced in the forward fuselage ahead of the engine.

Figures 22 through 25 are PSD plots for the equipment affected by this aircraft/engine combination.

- Figure 22 is the PSD for WRA's 53, 57, and 71.
- Figure 23 is the PSD for WRA's 12, 38, 39, 40, 46, 48, 80 and 87
- Figure 24 is the PSD for WRA's 11 and 12.
- Figure 25 is the PSD for WRA's 17, 88, 89 and 91.

Since the engines are mounted aft, vibration levels tend to be relatively low, (see figures 22 and 23). Higher levels are found in the engine zone (see figure 24). However, equipment mounted between engines on the aircraft ℄ see lower than expected levels.

Although a final profile recommendation will not be offered at this time (further investigation and analysis is required) certain observations can be made.

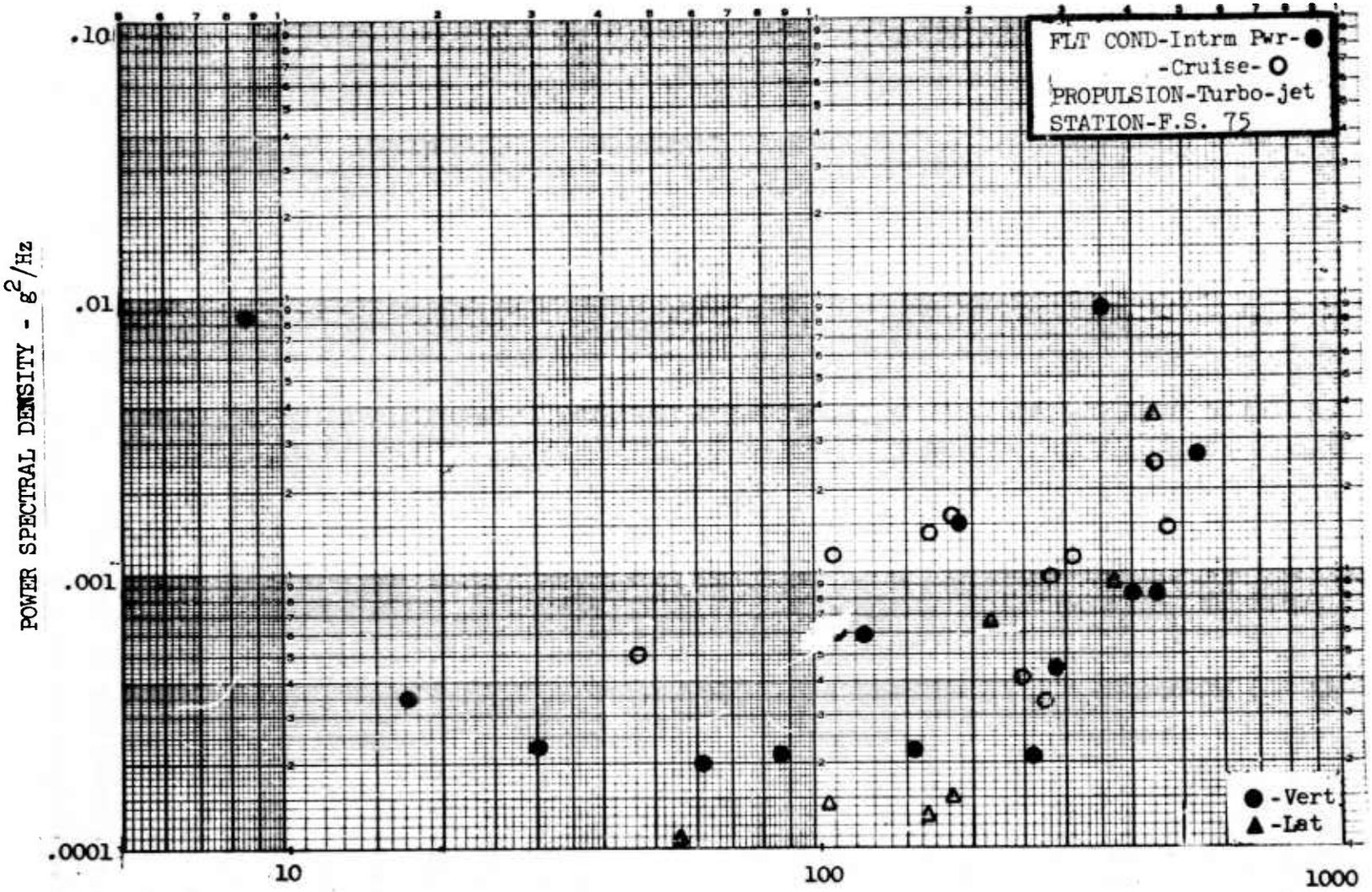


FIGURE 20 PSD PLOT FOR TURBO JET NO. 2 - CASE 1

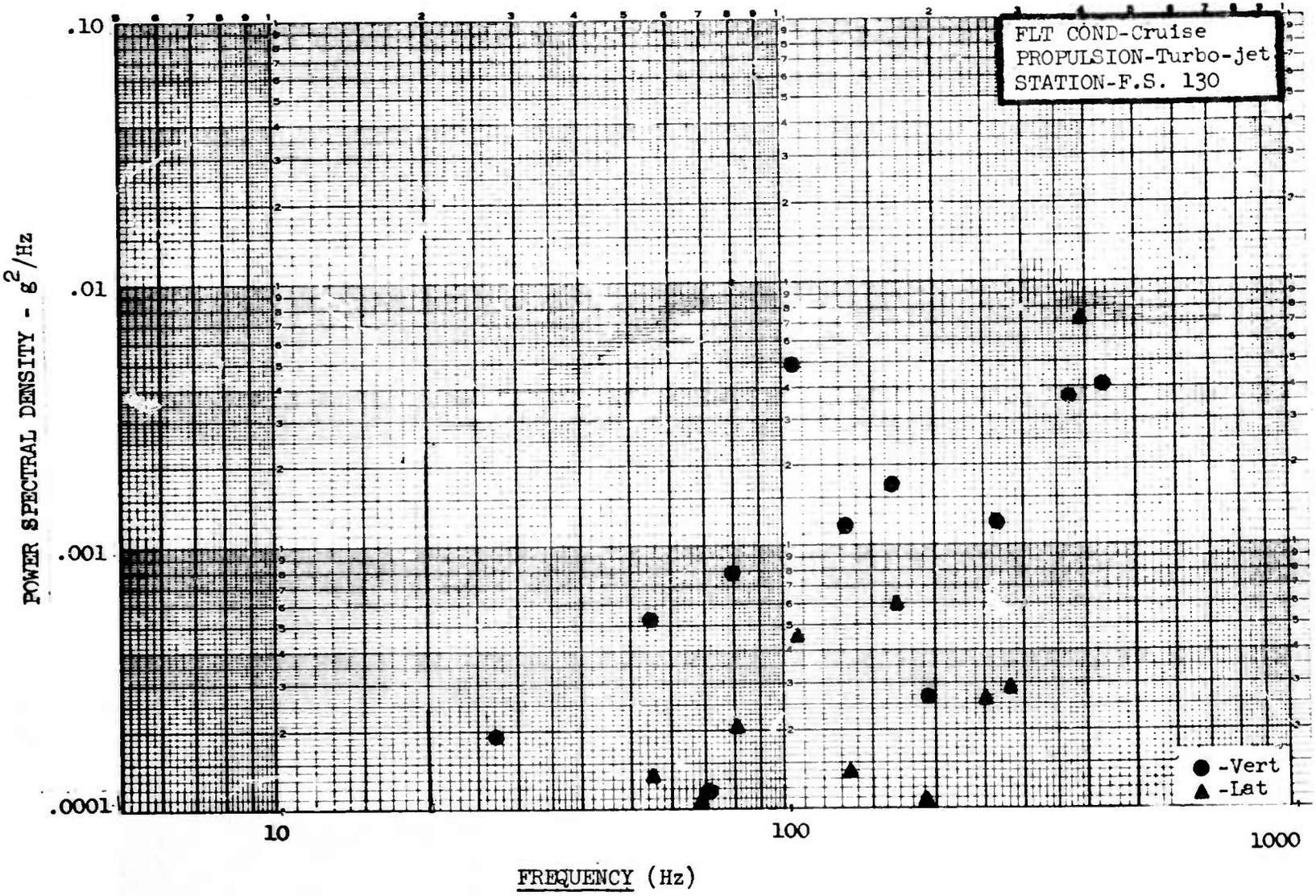


FIGURE 21 PSD PLOT FOR TURBO JET NO. 2 - CASE 2

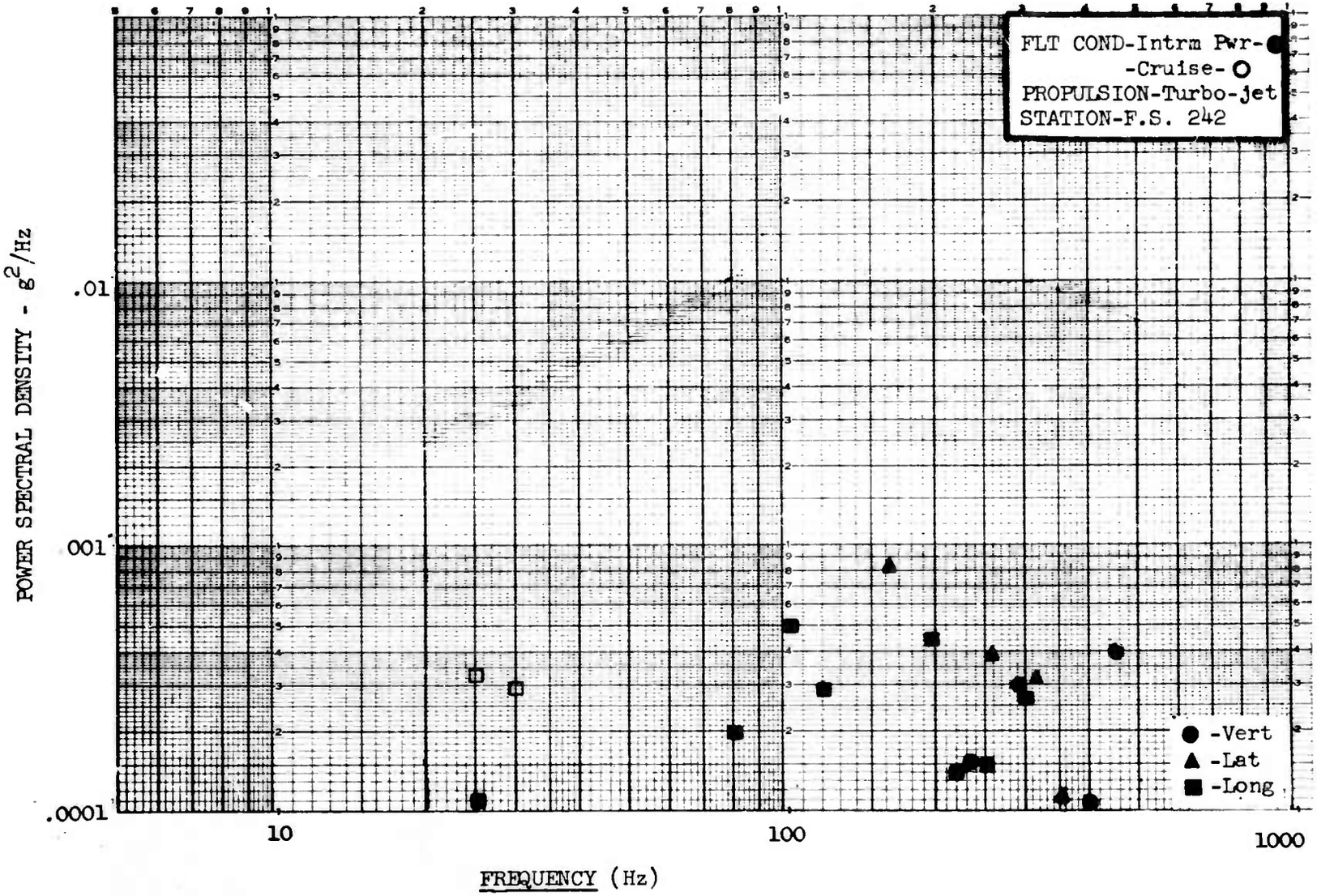


FIGURE 22 PSD PLOT FOR TURBO JET NO. 3 - CASE 1

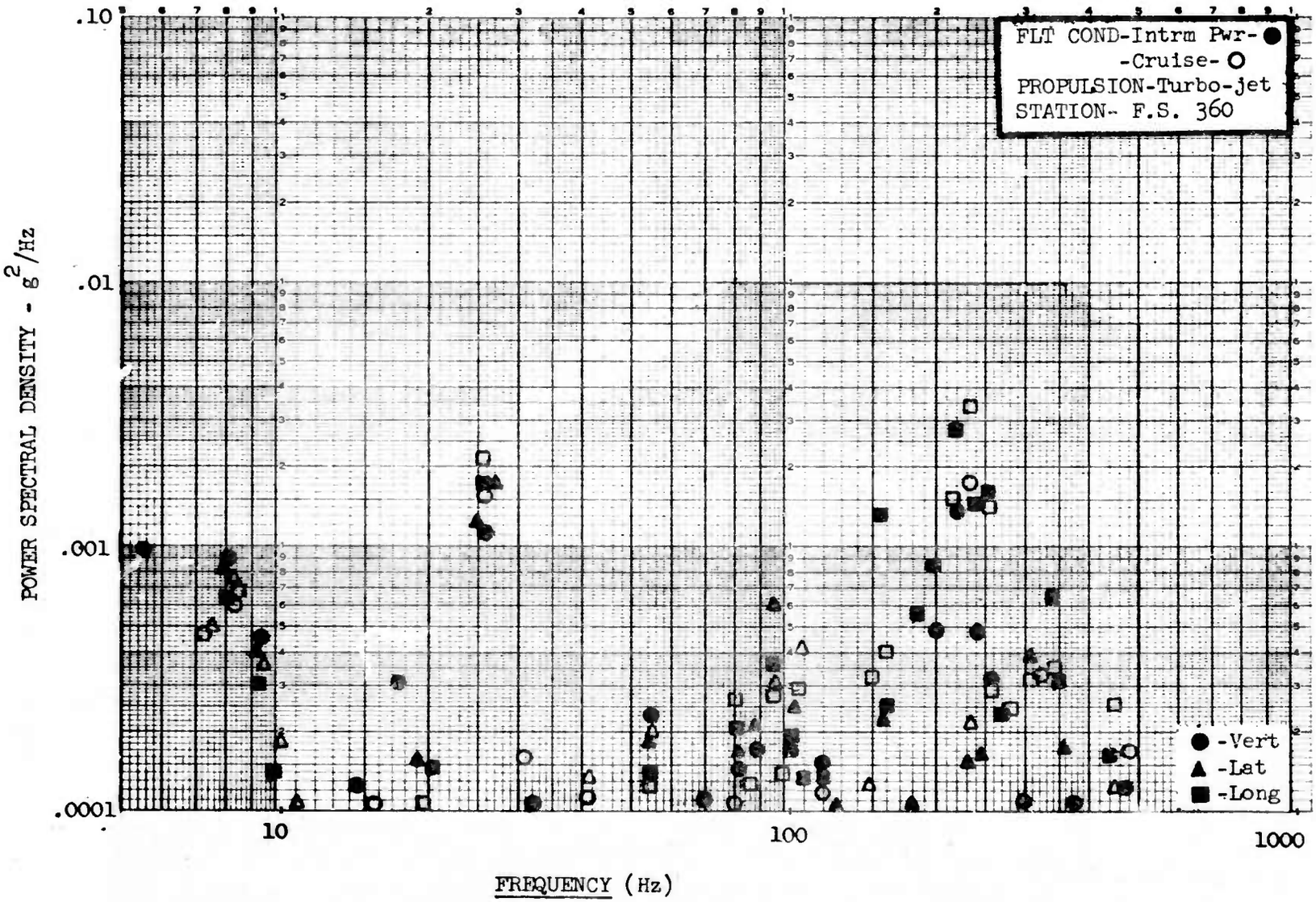


FIGURE 23 PSD PLOT FOR TURBO JET NO. 3 - CASE 2

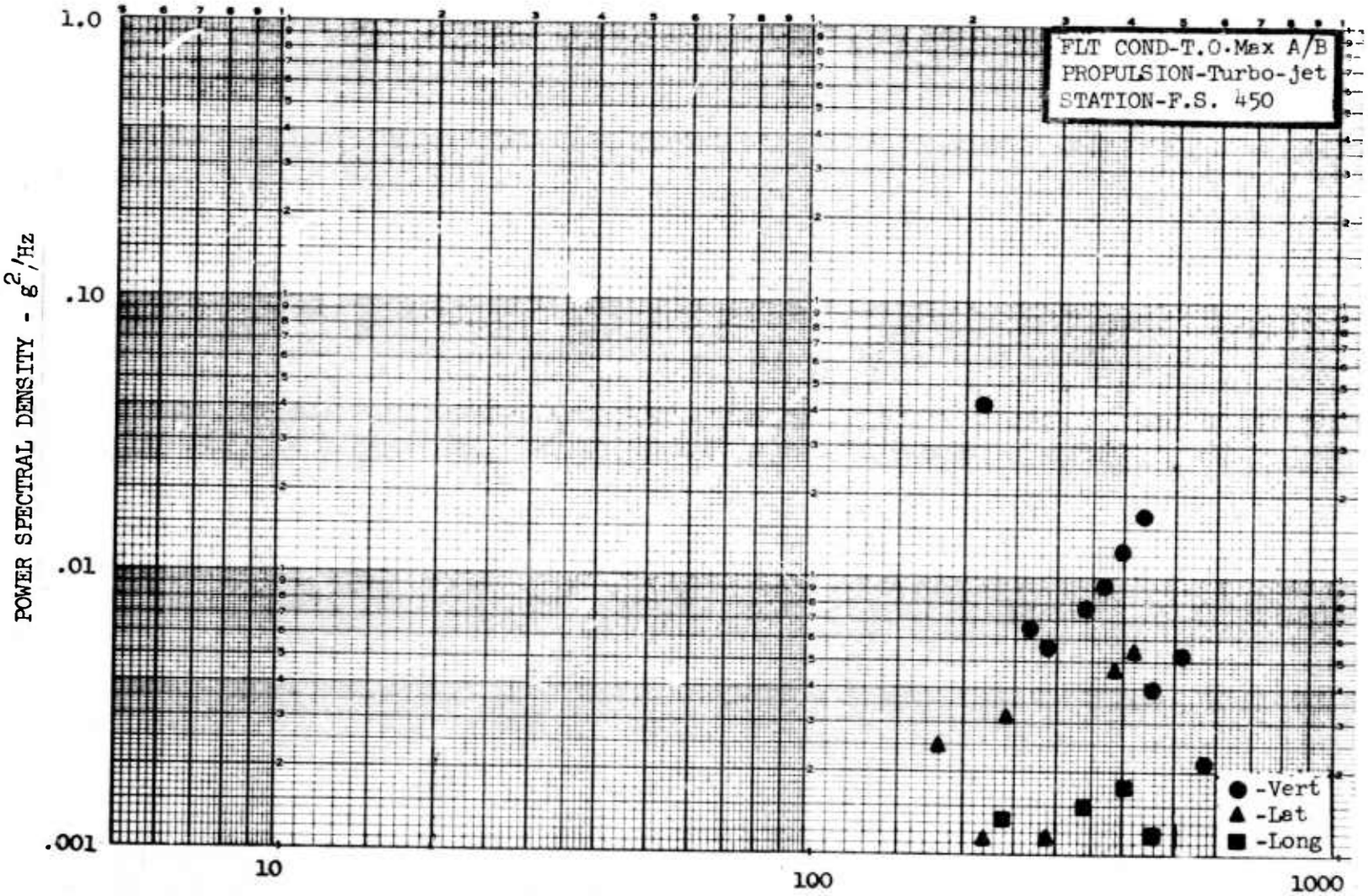


FIGURE 24 PSD PLOT FOR TURBO JET NO. 3 - CASE 3

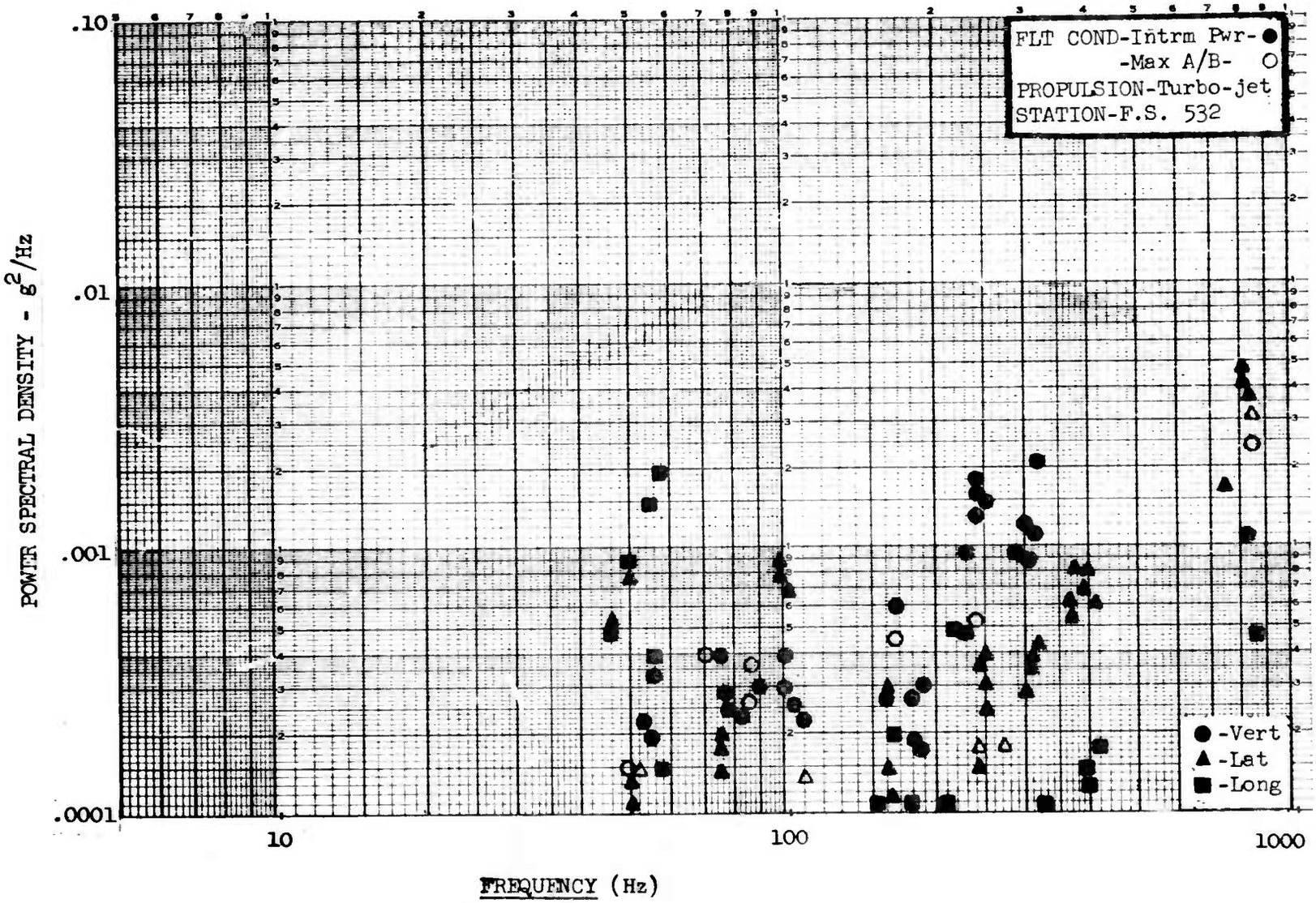


FIGURE 25 PSD PLOT FOR TURBO JET NO. 3 - CASE 4

In review of all the equipment vibration measurements evaluated for this study, the variation in the vibration content measured on the four (4) aircraft studied does not indicate one vibration envelope that would represent a realistic reliability demonstration level. To encompass in a single envelope the periodic frequencies present in the Prop-Jet, as well as the narrow and broad band random content in the Turbo-Jets' (in addition to the varying magnitudes across the fuselage for all the aircraft) would result in a severe and conservative test for a vast amount of equipment.

It appears that more than one spectrum will be required to adequately encompass variation in aircraft types as well as equipment location with respect to power plant location. Additionally, it is anticipated that durations of exposure will differ significantly from those now specified for reliability demonstration tests. Table 6 presents a comparison of field and laboratory vibration type and duration of exposure. The durations of exposure to permit a comparison of field and laboratory hours were derived as follows:

- Field duration - Since the equipment in a flight mode is subjected to constant vibration, the duration of exposure for the field was set equal to the total demonstration test operating time for each equipment.
- Laboratory duration - During the tests, vibration was applied for a fixed percentage of equipment operating time per test cycle. The total number of test operating hours was then multiplied by this percentage to establish the WRA vibration test hours.

In all cases the duration of exposure to vibration was greater in the field than during the test (for equivalent operating hours) and in the majority of cases the differences in time was significant. Since the majority of the aircraft studied were Turbo-Jet propelled, random vibration predominated as the mode of field excitation. All laboratory tests were performed under sine conditions.

TABLE 6 - VIBRATION PARAMETERS

WRA NO.	TYPE		DURATION (Hours)			WRA NO.	TYPE		DURATION (Hours)		
	LAB	FIELD	LAB	FIELD	Δ		LAB	FIELD	LAB	FIELD	Δ
1	Sine	Random	9.0	113	+104	25	Sine	Random	9.0	113	+104
2	Sine	Random	18	217	+199	26	Sine	Sine	684	831	+147
3	Sine	Random	70	562.5	+492.5	27	Sine	Random	293	1918	+1625
4	Sine	Random	9.0	113	+104	28	Sine	Random	9.0	113	+104
5	Sine	Random	70	550	+480	29	Sine	Sine	88	111	+23
6	Sine	Random	9.0	113	+104	30	Sine	Random	70	562.5	+492.5
7	Sine	Random	70	562.5	+492.5	31	Sine	Random	9.0	113	+104
8	Sine	Random	18	217	+199	32	Sine	Sine	684	831	+147
9	Sine	Sine	88	111	+23	33	Sine	Sine	88	111	+23
10	Sine	Random	9.0	113	+104	34	Sine	Sine	684	831	+147
11	Sine	Random	167	1328	+1161	35	Sine	Random	490	3540	+3050
12	Sine	Random	167	1328	+1161	36	Sine	Sine	88	111	+23
13	Sine	Random	70	562.5	+492.5	37	Sine	Random	293	1918	+1625
14	Sine	Sine	680	850	+170	38	Sine	Random	300	1790	+1490
15	Sine	Random	9.0	113	+104	39	Sine	Random	300	1790	+1490
16	Sine	Random	9.0	113	+104	40	Sine	Random	300	1790	+1490
17	Sine	Random	9.0	113	+104	41	Sine	Sine	684	831	+147
18	Sine	Random	9.0	113	+104	42	Sine	Sine	684	831	+147
19	Sine	Random	18	217	+199	43	Sine	Sine	684	831	+147
20	Sine	Random	70	550	+480	44	Sine	Random	70	550	+480
21	Sine	Sine	88	111	+23	45	Sine	Sine	680	850	+170
22	Sine	Random	70	550	+480	46	Sine	Random	177	1512	+1335
23	Sine	Sine	684	831	+147	47	Sine	Sine	684	831	+147
24	Sine	Random	161	1053	+892	48	Sine	Random	292	2330	+2038

TABLE 6 - VIBRATION PARAMETERS (Continued)

WRA NO.	TYPE		DURATION (Hours)		
	LAB	FIELD	LAB	FIELD	Δ
49	Sine	Sine	680	850	+170
50	Sine	Sine	9.0	113	+104
51	Sine	Sine	200	1700	+1500
52	Sine	Sine	684	831	+147
53	Sine	Sine	300	1790	+1490
54	Sine	Random	9.0	113	+104
55	Sine	Random	293	1918	+1625
56	Sine	Random	9.0	113	+104
57	Sine	Random	300	1790	+1490
58	Sine	Random	9.0	113	+104
59	Sine	Random	183	1200	+1017
60	Sine	Random	9.0	113	+104
61	Sine	Random	292	2330	+2038
62	Sine	Random	9.0	113	+104
63	Sine	Sine	88	111	+23
64	Sine	Random	9.0	113	+104
65	Sine	Random	292	2330	+2038
66	Sine	Random	70	550	+480
67	Sine	Random	9.0	113	+104
68	Sine	Random	70	562.5	+492.5
69	Sine	Sine	88	111	+23
70	Sine	Random	9.0	113	+104
71	Sine	Random	167	1328	+1161
72	Sine	Random	9.0	113	+104
73	Sine	Random	70	562.5	+492.5
74	Sine	Random	9.0	113	+104
75	Sine	Random	70	562.5	+492.5
76	Sine	Sine	684	831	+147
77	Sine	Random	9.0	113	+104
78	Sine	Sine	684	831	+147
79	Sine	Random	9.0	113	+104
80	Sine	Random	167	1328	+1161
81	Sine	Sine	684	831	+147
82	Sine	Random	70	562.5	+492.5
83	Sine	Random	9.0	113	+104
84	Sine	Sine	88	111	+23
85	Sine	Random	70	550	+480
86	Sine	Sine	684	831	+147
87	Sine	Random	300	1790	+1490
88	Sine	Random	300	1790	+1490
89	Sine	Random	300	1790	+1490
90	Sine	Sine	684	831	+147
91	Sine	Random	300	1790	+1490
92	Sine	Sine	88	111	+23
93	Sine	Sine	684	831	+147
94	Sine	Sine	88	111	+23
95	Sine	Sine	684	831	+147

3.2.4 Altitude

All selected study equipments are exposed to some low pressure condition during flight. Cockpit equipment however, is maintained at ambient pressures up to a given altitude (generally 8,000 feet) and then exposed to a controlled pressure (higher than ambient) up to the operational ceiling of the aircraft.

The effects of altitude are manifested in two ways:

- Steady state exposure
- Cycling effects due to aircraft altitude variations

Grumman experience indicates that the steady state condition generally causes problems due to a disruptive electric discharge (arc-over) causing serious damage to electronic components. The cycling conditions results in failures of gasket sealed enclosures permitting loss of gas or fluid and entry of moisture. Table 7 presents the field levels and rates of change for each equipment including the differences between field and lab. Since all laboratory testing was performed under sea level conditions (14.7 PSI) field conditions were more severe (lower pressure) in each case.

3.2.5 Input Voltage

All electric power, produced by on-board generating systems and supplied to airborne equipment at the equipment terminals, is controlled in accordance with the requirements of MIL-STD-704A (ref. 8). The input and voltages are maintained within the limits defined by this standard. In discussions with engineering and flight test personnel, actual measurements made of input voltage confirm the fact that those values are within the limits prescribed by MIL-STD-704A. Further, since laboratory voltages were also maintained within these tolerances, no deltas of significance exist between lab and field. However, the effects of transients and momentary power losses will be further investigated.

TABLE 7 - ATMOSPHERIC PRESSURE PARAMETERS

WRA NO.	LEVEL			RATE OF CHANGE		
	PSIA		Δ	PSI/MINUTE		Δ
	LAB	FIELD	PSIA	LAB	FIELD	PSI/MIN
1	14.7	2.14	-12.56	0	4	4
2	14.7	2.14	-12.56	0	4	4
3	14.7	2.7	-12.0	0	4	4
4	14.7	2.14	-12.56	0	4	4
5	14.7	2.14	-12.56	0	4	4
6	14.7	2.14	-12.56	0	4	4
7	14.7	2.7	-12.0	0	4	4
8	14.7	2.14	-12.56	0	4	4
9	14.7	8.5	-6.2	0	4	4
10	14.7	2.14	-12.56	0	4	4
11	14.7	0.65	-14.05	0	3	3
12	14.7	0.65	-15.05	0	3	3
13	14.7	2.7	-12.0	0	4	4
14	14.7	8.5	-6.2	0	4	4
15	14.7	2.14	-12.56	0	4	4
16	14.7	2.14	-12.56	0	4	4
17	14.7	2.14	-12.56	0	4	4
18	14.7	2.14	-12.56	0	4	4
19	14.7	2.14	-12.56	0	4	4
20	14.7	2.14	-12.56	0	4	4
21	14.7	8.5	-6.2	0	4	4
22	14.7	2.14	-12.56	0	4	4
23	14.7	8.5	-6.2	0	4	4
24	14.7	2.7	-12.0	0	4	4
25	14.7	2.14	-12.56	0	4	4
26	14.7	8.5	-6.2	0	4	4
27	14.7	7.7	-7.0	0	4	4
28	14.7	2.14	-12.56	0	4	4
29	14.7	8.5	-6.2	0	4	4
30	14.7	2.7	-12.0	0	4	4
31	14.7	2.14	-12.56	0	4	4
32	14.7	8.5	-6.2	0	4	4
33	14.7	8.5	-6.2	0	4	4

TABLE 7 - ATMOSPHERIC PRESSURE PARAMETERS (Continued)

WRA NO.	LEVEL			RATE OF CHANGE		
	PSIA		Δ	PSI/MINUTE		Δ
	LAB	FIELD	PSIA	LAB	FIELD	PSI/MIN
34	14.7	8.5	-6.2	0	4	4
35	14.7	2.14	-12.56	0	4	4
36	14.7	8.5	-6.2	0	4	4
37	14.7	7.7	-7.0	0	4	4
38	14.7	0.65	-14.05	0	3	3
39	14.7	0.65	-14.05	0	3	3
40	14.7	0.65	-14.05	0	3	3
41	14.7	8.5	-6.2	0	4	4
42	14.7	8.5	-6.2	0	4	4
43	14.7	8.5	-6.2	0	4	4
44	14.7	2.14	-12.56	0	4	4
45	14.7	8.5	-6.2	0	4	4
46	14.7	0.65	-14.05	0	3	3
47	14.7	8.5	-6.2	0	4	4
48	14.7	0.65	-14.05	0	3	3
49	14.7	8.5	-6.2	0	4	4
50	14.7	2.14	-12.56	0	4	4
51	14.7	8.5	-6.2	0	4	4
52	14.7	8.5	-6.2	0	4	4
53	14.7	5.65	-9.05	0	3	3
54	14.7	2.14	-12.56	0	4	4
55	14.7	7.7	-7.0	0	4	4
56	14.7	2.14	-12.56	0	4	4
57	14.7	5.65	-9.05	0	3	3
58	14.7	2.14	-12.56	0	4	4
59	14.7	7.7	-7.0	0	4	4
60	14.7	2.14	-12.56	0	4	4
61	14.7	5.65	-9.05	0	3	3
62	14.7	2.14	-12.56	0	4	4
63	14.7	8.5	-6.2	0	4	4
64	14.7	2.14	-12.56	0	4	4
65	14.7	5.65	-9.05	0	3	3
66	14.7	2.14	-12.56	0	4	4

TABLE 7 - ATMOSPHERIC PRESSURE PARAMETERS (Continued)

WRA NO.	LEVEL			RATE OF CHANGE		
	PSIA		Δ	PSI/MINUTE		Δ
	LAB	FIELD	PSIA	LAB	FIELD	PSI/MIN
67	14.7	2.14	-12.56	0	4	4
68	14.7	7.7	-7.0	0	4	4
69	14.7	8.5	-6.2	0	4	4
70	14.7	2.14	-12.56	0	4	4
71	14.7	5.65	-9.05	0	3	3
72	14.7	2.14	-12.56	0	4	4
73	14.7	7.7	-7.0	0	4	4
74	14.7	2.14	-12.56	0	4	4
75	14.7	7.7	-7.0	0	4	4
76	14.7	8.5	-6.2	0	4	4
77	14.7	2.14	-12.56	0	4	4
78	14.7	8.5	-6.2	0	4	4
79	14.7	2.14	-12.56	0	4	4
80	14.7	0.65	-14.05	0	3	3
81	14.7	8.5	-6.2	0	4	4
82	14.7	2.7	-12.0	0	4	4
83	14.7	2.14	-12.56	0	4	4
84	14.7	8.5	-6.2	0	4	4
85	14.7	2.14	-12.56	0	4	4
86	14.7	8.5	-6.2	0	4	4
87	14.7	0.65	-14.05	0	3	3
88	14.7	0.65	-14.05	0	3	3
89	14.7	0.65	-14.05	0	3	3
90	14.7	8.5	-6.2	0	4	4
91	14.7	0.65	-14.05	0	3	3
92	14.7	-	-	-	-	-
93	14.7	8.5	-6.2	0	4	4
94	14.7	-	-	-	-	-
95	14.7	8.5	-6.2	0	4	4

SECTION IV

MTBF ANALYSIS

4.1 Demonstration

Although the major study emphasis is directed toward environmental differences, it was also recognized that other factors, including ground rules, might also contribute significantly to differences in MTBF. During the reliability demonstration tests performed on the selected equipment, definitions per MIL-STD-721 (ref. 9) and ground rules specified in MIL-STD-781 and AR-34 (ref. 2, 10), were generally employed. These were modified and/or supplemented in varying degree for each of the equipment tests performed. Since a lab demonstration is intended to verify that an equipment has met a specified MTBF (at some confidence level), the value so demonstrated should be reflected in the same equipment during field operation. Failure scoring criteria for field and lab must therefore be compatible and a realistic set of ground rules must be defined. During this study all ground rules and definitions were reviewed, including those appearing in AR-34, MIL-STD-781, MIL-STD-721 and those peculiar to each of the study equipment tests. The rules obtained from these sources were then screened and either rejected, used as-is, modified or supplemented. This review was based on the premise that field and lab θ's must be derived in an identical manner using the same scoring criteria for failure classification. The set of "standard" rules established was then applied to each of the demonstration tests resulting in reclassified failures and revised θ's. The following rules were established and used to classify failures:

FAILURE

A failure is the cessation of equipment operation or an out-of-specification condition of a performance characteristic at any specified environmental condition.

RELEVANT FAILURES

All failures are relevant unless determined by the procuring activity (or an authorized representative thereof) to be caused by a condition external to the equipment under test which is not a test requirement. Relevant failures include:

- Design/Workmanship Failures: Failures due to design deficiencies or poor workmanship of either the equipment or component parts.

- Component Part Failures: Failures due to defective component parts shall be classified as relevant failures. In the event that several component parts of the same type fail during the test, each one shall be considered a separate relevant failure, unless it can be shown that one failure caused one or more of the others.

- Wearout Parts: Certain parts of known limited life, such as batteries, may have a life stipulated prior to the initiation of testing as approved by the procuring activity. Failures of these parts occurring prior to the end of the stipulated period are relevant. Failures of these parts occurring after the stipulated period are nonrelevant, but any dependent failures caused thereby are relevant.

- Multiple Failures: In the event simultaneous part failure occur, each failed part which would independently prevent satisfactory equipment performance shall be counted as a relevant failure except as follows: If the contractor and the procuring activity agree that the failure of one part was entirely responsible for the failure of any other parts, then each such dependent part failure shall not be counted as a relevant failure. At least one equipment relevant failure shall be counted when a dependent failure is claimed.

- Intermittent Failures: The first occurrence of an intermittent failure on any one equipment shall be counted as a relevant failure, although subsequent occurrences of the same intermittency on that same unit will be considered nonrelevant.

- Adjustments:

  - Anticipation of failure shall not be justification for preventive maintenance, i.e., if an output is observed to be degrading but is still within specification limits. No replacement is permitted and any adjustment of a control is a relevant failure unless both the control and the indicator signaling impending failure are an integral part of the equipment under test and are available and accessible to the aircrew during normal flight operation.

- Inaccessible Controls - Each adjustment of a control which is inaccessible to the operator during normal use is a relevant failure.

- Failures of Built-in-Test: Any malfunction (including a false alarm) of the Built-in-Test features of the equipment shall be classified as a relevant failure.

- Failures During "Down Time": Failures occurring and/or detected during test "down time" shall be scored as relevant (unless proven that they were induced by maintenance).

  - If a failure occurs during the test, a WRA is removed for repair, the item causing the removal isolated and repaired and then, other problems are discovered (unrelated to the original problem), separate failures shall be counted for each discrepancy.

  - All failures (unless they are due to secondary effects) occurring during troubleshooting on-time and during repair verification shall be scored relevant.

- When a failure occurs and a change is incorporated (design, part or process) which will correct the problem, the first occurrence shall be scored relevant and all subsequent failure of the same type occurring during the test but before corrective action has been incorporated shall be nonrelevant.

- Failures detected during the final functional test following the successful completion of the test shall be scored relevant, if the equipment used to monitor the performance characteristics was not capable of detecting that failure.

NON-RELEVANT FAILURES

Only those failures listed below may be counted as non-relevant.

- Failures directly attributable to improper installation in the test chamber.

- Failures of test instrumentation or monitoring equipment (other than the Built-in Test function).
- Failures resulting from test operator error in setting up, or in testing the equipment.
- Dependent failures, unless caused by degradation of items of known limited life. (At least one relevant failure shall be counted when a dependent failure is claimed.)
- Failures attributable to an error in the test procedures.
- The second (and any subsequent) occurrences of the same intermittent failure on the same unit.
- Failures occurring during burn-in.
- Malfunctions of the Time Totalizing Meters.
- Failures clearly attributable to an overstress condition in excess of the design requirements.

RECLASSIFICATION

A failure, classified as relevant, may be reclassified to nonrelevant provided that all of the following conditions are met:

- Corrective action (an equipment design, part, or production process change) has been made in accordance with the applicable reliability test specification or standard on all equipment of the lot from which the reliability test sample was drawn, and;
- Sufficient test data has been accumulated to indicate the corrective action is effective in eliminating the failure mode, and;
- Approval of the procuring activity (or authorized representative) is obtained for reclassification of the failure.

NOTE: The first occurrence of such a failure shall be scored relevant.

Table 8 shows the equipment MTBF's demonstrated under the ground rules and scoring criteria in effect at the time of testing. Revised values after reclassifying failures with the above ground rules are also presented. It is interesting to note that the average value went from 15,800 hours before

TABLE 8 DEMONSTRATED MTBF VALUES

WRA NUMBER	DEMONSTRATED MTBF BEFORE RECLASSIFYING	DEMONSTRATED MTBF AFTER RECLASSIFYING	WRA NUMBER	DEMONSTRATED MTBF BEFORE RECLASSIFYING	DEMONSTRATED MTBF AFTER RECLASSIFYING
1	381	381	27	417	334
2	164	164	28	618	618
3	212	41	29	312	134
4	361	361	30	1,969	382
5	2,506	1,736	31	2,203	2,203
6	226	226	32	7,813	1,307
7	665	129	33	198	28
8	164	164	34	66,667	10,870
9	421	45	35	5,102	3,540
10	226	226	36	1,745	748
11	3,378	1,206	37	347	278
12	7,299	2,611	38	9,434	9,434
13	497	97	39	8,696	8,696
14	1,527	508	40	10,638	10,638
15	38,462	38,462	41	55,556	2,336
16	38,462	38,462	42	62,500	2,591
17	743	743	43	58,824	2,439
18	38,462	38,462	44	2,049	1,420
19	612	612	45	1,776	591
20	4,184	2,898	46	756	168
21	442	47	47	9,091	24
22	22,222	15,385	48	1,129	403
23	3,861	645	49	883	294
24	1,054	526	50	370	370
25	2,898	2,898	51	2,453	2,453
26	3,279	546	52	5,917	985

TABLE 8 DEMONSTRATED MTBF VALUES (Continued)

WRA NUMBER	DEMONSTRATED MTBF BEFORE RECLASSIFYING	DEMONSTRATED MTBF AFTER RECLASSIFYING	WRA NUMBER	DEMONSTRATED MTBF BEFORE RECLASSIFYING	DEMONSTRATED MTBF AFTER RECLASSIFYING
53	100,000	100,000	75	1,189	231
54	1,426	1,426	76	14,085	2,331
55	1,024	819	77	5,586	5,586
56	12,195	12,195	78	83,333	14,085
57	200,000	200,000	79	3,300	3,300
58	6,289	6,289	80	1,092	390
59	1,732	1,732	81	15,625	162
60	7,874	7,874	82	1,582	308
61	1,580	564	83	4,184	4,184
62	12,500	12,500	84	405	43
63	2,000	857	85	10,753	7,463
64	62,500	62,500	86	20,833	882
65	1,597	571	87	16,949	16,949
66	13,158	9,091	88	16,949	16,949
67	910	910	89	11,236	11,236
68	789	153	90	76,923	12,346
69	1,462	627	91	50,000	50,000
70	988	988	92	125,000	52,632
71	1,901	678	93	27,777	4,673
72	6,993	6,993	94	125,000	52,632
73	1,043	203	95	14,706	2,457
74	1,159	1,159			

reclassifying to 9,500 hours after. This represents a decrease of approximately 40% in the average value.

4.2 Field

Consistency in failure definition and time measurement is necessary to assure that field-lab reliability comparisons are valid. Estimates of MTBF in the field should be determined from equipment operating time and the number of equipment failures experienced during that operating time. All too often, because of inability to discriminate in data, field MTBF's are reported as the resulting quotient after dividing aircraft flight time by the total number of maintenance actions reported. This measure, referred to as Mean Flight Time Between Maintenance Action (MFTBMA), though perhaps having value for Operations personnel for planning and resource control, is not comparable with either predicted or demonstrated MTBF's. Whereas, the MFTBMA counts all incidents (i.e., failures, false alarms, preventive maintenance, cannibalization, induced failures, etc.), demonstration test ground rules exclude every type of incident except a bona fide failure. And, as indicated previously, it has not been uncommon for test ground rules to exclude some legitimate failures as well. In addition to failure count definition not being compatible, the substitution of aircraft flight time for equipment operating time creates artificial differences in field-demonstration reliability comparisons. Flight hours may differ from equipment operating hours by such factors as duty cycle, ground operating time while installed in an aircraft, and bench time.

Thus, both numerator and denominator of an MFTBMA does not relate to the usual definition of MTBF. Except for those items that have a very short duty cycle, equipment operating time is longer than flight time. Usually the number of equipment failures is less than the number of maintenance actions. Therefore, MFTBMA is less, often much less, than MTBF. And if, as indicated previously, test ground rules have eliminated some bona fide failures from the count, then the disparity between lab demonstrated and field measured reliability is even greater.

The analyses that were performed on the field data to bring it to a common basis with the lab included evaluating equipment operating time and determining the number of equipment failures in accordance with ground rules established to be comparable to those established for the lab MTBF analysis.

Equipment Operating Time: Maintenance personnel are required to note the serial number and Elapsed Time Indicator (ETI) reading on every item removed from or installed in an aircraft. Although this requirement is not rigidly enforced, it is adhered to sufficiently to provide useful data for analysis. The analysis goal was to develop a factor which when multiplied by aircraft flight hours would yield equipment operating hours. This approach was necessitated by the fact that total aircraft flight times are readily available in the data system whereas total equipment operating times are not. A sample of data points was assembled for each equipment where each data point represents the difference in ETI readings between installation and removal of a given serial number from a particular aircraft. Since the dates of installation and removal are given, the corresponding aircraft flight time between installation and removal dates was determined for each ETI difference. The average ratio of ETI difference to flight time was determined for most equipment in this manner. For any equipment where insufficient data existed to develop its own ratio, the ratio of an equipment whose operating profile most closely resembles it was used. Each such ratio multiplied by total aircraft flight time became the estimate of total equipment operating time.

Failure Frequency: Field Failure Criteria were developed in a manner similar to and compatible with those developed for demonstration. For the analysis at this time, all incidents were considered relevant and counted unless the equipment was:

- bad from supply.
- removed for preventive maintenance.
- removed for the convenience of the maintenance crew to gain access to another equipment
- removed from an aircraft and not verified bad in the shop
- removed for modification
- crabbed and not verified while still installed in the aircraft
- damaged as a result of abuse, combat, mishandling, etc.
- part of a cannibalization action

Future analyses will assess the impact of flight discovered anomalies that could not be verified by the ground crew. Since the flight and ground environments are different, it is reasonable to expect at least some equipment malfunctions will be observable only in the presence of a flight environment. In addition, a more precise identification of nonrelevant failures will be made by a more detailed review and comparison of failure modes.

Two estimates of equipment field MTBF are presented in Table 9. Each represents the results of a review of the equipment failure history for all of 1973 and, in some cases, the first quarter of 1974. The first estimate is the equipment MFTBMA and results from dividing aircraft flight time by total maintenance actions. The second measure is the resultant value after dividing estimated equipment operating time by the number of reclassified failures. It is this second measure that is comparable to demonstration results. As an indicator of the impact of reclassifying field failures, the average value goes from 1200 hours for the first measure to 3300 for the second. This is an increase of approximately 175%.

Impact of Ground Rules: Though it is a crude barometer, examination of average values before and after applying the previously described ground rules provides some insight into how generally applied ground rules and scoring criteria impact field-lab MTBF comparisons. The average demonstrated MTBF value was 15,800 hours before reclassifying and 9500 after. Similarly, the average field MTBF value was 1200 hours before and 3300 hours after. A lab-field comparison made on the averages of the raw data would show the MTBF's to be in approximately a 13:1 ratio (15,800:1200) while a similar comparison performed on resulting reclassified values would show only a 3:1 ratio (9500: 3300). Even though averages of averages are used in the comparison, it roughly indicates the extent to which incompatible ground rules may exaggerate the difference between lab and field MTBF's and should provide a caution to anyone making such comparisons to assure the consistency of the data.

It is noted that an area of inconsistency in redefined failure scoring criteria exists between lab and field. This occurs when counting additional failures during down-time. The lab scoring groundrules require that each separate problem occuring during down-time is counted as a relevant failure.

The field groundrules count each pertinent maintenance action as a relevant failure regardless of how many problems/part failures are corrected during the repair action. The effect of these groundrules is to understate the lab MTBF and/or overstate the field MTBF, thus, generally driving down the relative difference between the two measures. Thus, the 3:1 ratio is the best that can be achieved and is probably higher. However, preliminary observations indicate that if this inconsistency were removed, the resulting ratio would be closer to the 3:1 figure than to the 13:1 ratio. Future analyses will resolve this inconsistency.

TABLE 9 FIELD MTBF VALUES

WRA NUMBER	FIELD MTBF (MFTBMA)	FIELD MTBF AFTER RECLASSIFICATION	WRA NUMBER	FIELD MTBF (MFTBMA)	FIELD MTBF AFTER RECLASSIFICATION
1	111	246	27	73	240
2	297	90	28	35	111
3	30	144	29	154	143
4	66	127	30	122	780
5	343	584	31	387	738
6	65	210	32	1,076	5,903
7	76	296	33	917	847
8	120	42	34	2,153	2,045
9	227	1,141	35	76	646
10	51	139	36	3,107	1,654
11	2,000	55,996	37	138	595
12	6,666	53,868	38	333	2,444
13	72	331	39	238	7,333
14	431	954	40	175	1,466
15	12,850	17,347	41	615	2,045
16	4,452	12,022	42	2,153	5,903
17	65	194	43	861	4,091
18	12,850	17,347	44	43	33
19	194	89	45	431	2,753
20	131	72	46	10	42
21	2,153	3,293	47	718	2,337
22	424	738	48	152	1,042
23	135	409	49	308	636
24	89	268	50	28	138
25	330	2,389	51	51	313
26	308	2,045	52	239	292

TABLE 9 FIELD MTBF VALUES (Continued)

WRA NUMBER	FIELD MTBF (MFTBMA)	FIELD MTBF AFTER RECLASSIFICATION	WRA NUMBER	FIELD MTBF (MFTBMA)	FIELD MTBF AFTER RECLASSIFICATION
53	1,667	10,581	75	59	359
54	283	1,113	76	215	511
55	298	590	77	618	281
56	495	801	78	2,153	2,045
57	238	917	79	59	150
58	234	546	80	133	848
59	134	162	81	8,612	11,805
60	312	1,002	82	136	796
61	85	287	83	101	398
62	278	1,202	84	269	3,293
63	3,107	1,654	85	524	430
64	424	572	86	4,306	5,903
65	98	347	87	3,333	10,581
66	318	172	88	1,667	7,333
67	56	135	89	3,333	10,581
68	72	252	90	215	409
69	718	382	91	4,810	10,581
70	56	135	92	3,107	1,654
71	175	933	93	3,107	2,951
72	312	751	94	3,107	1,654
73	98	381	95	1,076	2,045
74	76	199			

SECTION V

PRELIMINARY ANALYSIS

5.1 Analysis Method

The primary purpose of this task is to identify those factors that tend to influence differences between the lab and the field MTBFs. This is being accomplished by relating, one at a time, environmental differences and WRA characteristics to MTBF differences and noting how MTBF differences change with changes in the factor under investigation. Future analyses will examine the joint effect of the factors taken several at a time. Quantitative relationships will be developed between the factors and MTBF differences to permit estimation of expected field reliability from prior knowledge of WRA characteristics and environmental requirements.

The first step in the analysis consisted of determining the ratio between reclassified demonstrated and reclassified field MTBF for each WRA and to use these ratios as the measure of the difference between lab and field. This measure was selected since it eliminates biases caused by using absolute magnitudes and normalizes the data to a common reference point. (A difference of 500 hours in a 10,000 hour box is not as severe as in a 1000 hour box.) Then, for each factor considered, categories of the factor were defined. For example, if the factor being analyzed was weight, the weight categories were; under 20 pounds (light), 21-40 pounds (medium), and over 40 pounds (heavy). The distribution of MTBF ratios for each category was then determined and summarized in a series of tables as illustrated below:

MTBF Ratio	Category 1	Category 2	Category 3
≤ 1.25	A	C	E
> 1.25	B	D	F
	100%	100%	100%

A ratio of 1.25 was selected as the point of discrimination between good and poor correlation between field and lab. A ratio of less than 1.25 means that the demostrated MTBF was no more than 25% higher than the field or that field value was higher than that demonstrated. A ratio of over 1.25 means that the

demonstrated MTBF was at least 25% higher than the field. The number in cell "B" then is the percent of category 1 WRAs whose demonstrated MTBF was at least 25% higher than its field value. The underlying premise for these analyses is that if the factor was not related to MTBF differences, the ratios would be distributed similarly for each category. Ideally, under this premise:

Cell "A" value = Cell "C" value = Cell "E" value, and

Cell "B" value = Cell "D" value = Cell "F" value

Conversely, if MTBF differences were correlated with the factor under consideration, the values in a row would be different from each other and the variation from category to category would provide some insight into the nature of the relationship between the factor and MTBF differences. These summary tables were prepared for several WRA characteristics as well as for differences in environment between field and lab.

5.2 WRA Characteristics

The relationship between the MTBF ratios and several WRA characteristics are summarized in Table 10 below. Preliminary conclusions that may be drawn from these tables are:

Function: Displays and controls as well as electromechanical devices have the poorest field performance relative to the lab while computers and power supplies have the best. Crew abuse and inadequate duplication of field on/off cycling/usage in the lab could explain the poor showing of controls and displays. Premature wearout or adjustment requirements may explain electromechanical equipment disparity.

Vintage: Older items correlate poorly while newer ones do better. This may result from more comprehensive reliability programs and more extensive use of high reliability parts in recent years.

Propulsion: WRAs installed in jet aircraft do worse than those installed in propeller driven planes. This may be explained by the fact that vibration testing in lab (sinusoidal) more closely duplicates the environment seen in propeller aircraft than that of jet aircraft (random).

Weight: No strong conclusion can be drawn although there seems to be a tendency for light and heavy WRAs to do worse than moderate weight boxes.

TABLE 10 DISTRIBUTION OF MTBF RATIOS FOR SELECTED WRA CHARACTERISTICS

FUNCTION

MTBF RATIO	RF RECEIVERS & TRANSMITTERS	SIGNAL PROCESSING	INTERFACE EQUIPMENT	COMPUTERS	DISPLAYS & CONTROLS	POWER SUPPLIES, SWITCHING	ELECTRO-MECHANICAL	RACKS, CABINETS
≤ 1.25	40%	42%	50%	56%	20%	56%	20%	40%
> 1.25	60	58	50	44	80	44	80	60

VINTAGE

MTBF RATIO	BEFORE 1970	1970 AND BEYOND
≤ 1.25	22	66
> 1.25	78	34

PROPULSION

MTBF RATIO	JET	PROP.
≤ 1.25	28	65
> 1.25	72	35

WEIGHT (LBS)

MTBF RATIO	UNDER 20	21 - 40	OVER 40
≤ 1.25	34	52	31
> 1.25	66	48	69

HEAT DISSIPATION (WATTS)

MTBF RATIO	0 - 75	76 - 200	> 200
≤ 1.25	28	42	56
> 1.25	72	58	44

COOLING

MTBF RATIO	AMBIENT	SUPPLEMENTAL COOLING REQUIRED
≤ 1.25	28	48
> 1.25	72	52

COOLING METHOD

MTBF RATIO	FORCED AIR	COLD PLATE
≤ 1.25	47	71
> 1.25	53	29

TABLE 10 DISTRIBUTION OF MTBF RATIOS FOR SELECTED WRA CHARACTERISTICS (Continued)

MOUNTING METHOD

MTBF RATIO	HARD	ISOLATOR
≤ 1.25	33	50
> 1.25	67	50

PACKAGING DENSITY (PARTS/IN.^{3})

MTBF RATIO	≤ .50	.51 - 2.00	> 2.00
≤ 1.25	25	42	59
> 1.25	75	58	41

PERCENT MICROCIRCUITS

MTBF RATIO	≤ 25%	26% - 50%	> 50%
≤ 1.25	34	45	73
> 1.25	66	55	27

Heat Dissipation: Since the low wattage WRAs are the ones that are ambient cooled, the cooling method is affecting the relationship.

Cooling: WRAs that do not have supplemental cooling have a poorer field-lab correlation than those that do.

Cooling Method: Cold plate cooled WRAs have a much better field-lab correlation than those that are forced air cooled. This may be associated with field-lab differences in the ability to keep deleterious substances out of the cooling air.

Mounting Method: No strong conclusion. There is a small tendency for isolator mounted WRAs to correlate better than hard mounted ones.

Percent Microcircuits: The higher the use of microcircuits in an equipment, the closer field and lab MTBFs are to each other.

Packaging Density: It appears that the correlation gets better as the packaging density increases. This tends to defy intuition but, may be very closely related to the above conclusions on supplemental cooling, cooling method and percent microcircuits.

5.3 Environmental Differences

In a similar manner, the environmental differences listed in Tables 4, 5, 6, and 7 were associated with the above MTBF ratios. The results of this analysis are presented in Tables 11, 12, 13, and 14, and are discussed below.

Ambient Temperature: Table 11 is a summary for all WRAs of ambient temperature range, rate of change, and duration at extremes. At first glance, the result appears contradictory in that it suggests that poorer MTBF correlation is associated with WRAs that see a less severe environment and are exposed to extremes for a shorter equivalent duration in the field than in the lab. Field-lab correlation, however, is better when the temperature rate of change is less than the lab. The results suggest, when viewed together, that:

- ambient temperatures during testing are perhaps too extreme
- no benefit is derived by having the WRA sit at extremes for long periods of time
- frequent and more rapid temperature changes during test are desirous.

TABLE 11 DISTRIBUTION OF MTBF RATIOS FOR AMBIENT TEMPERATURE DIFFERENCES - ALL WRAs

AMBIENT TEMPERATURE - LOW

MTBF RATIO	COLDER THAN LAB	WARMER THAN LAB
≤ 1.25	67	23
> 1.25	33	77

AMBIENT TEMPERATURE - HIGH

MTBF RATIO	COLDER THAN LAB	WARMER THAN LAB
≤ 1.25	33	47
> 1.25	67	53

AMBIENT AIR TEMPERATURE RATE OF CHANGE

MTBF RATIO	LESS THAN LAB	GREATER THAN LAB
≤ 1.25	55	39
> 1.25	45	61

DURATION AMBIENT TEMPERATURE - LOW

MTBF RATIO	LAB LONGER		FIELD LONGER
	> TWICE FIELD	< TWICE FIELD	
≤ 1.25	16	39	71
> 1.25	84	61	29

DURATION AMBIENT TEMPERATURE - HIGH

MTBF RATIO	LAB LONGER	LAB SHORTER
≤ 1.25	29	51
> 1.25	71	49

TABLE 12 DISTRIBUTION OF MTBF RATIOS FOR AMBIENT TEMPERATURE DIFFERENCES - AMBIENT COOLED WRAs

AMBIENT TEMPERATURE - LOW

MTBF RATIO	COLDER THAN LAB	1 - 75° WARMER	> 75° WARMER
≤ 1.25	83	44	7
> 1.25	17	56	93

AMBIENT TEMPERATURE - HIGH

MTBF RATIO	WARMER THAN LAB	0 - 25° COLDER	> 25° COLDER
≤ 1.25	50	31	28
> 1.25	50	69	72

AMBIENT AIR TEMPERATURE RATE OF CHANGE

	GREATER THAN LAB	LESS THAN LAB
≤ 1.25	26	56
> 1.25	74	44

TABLE 13 DISTRIBUTION OF MTBF RATIOS FOR SUPPLEMENTAL COOLING AIR DIFFERENCES

COOLING AIR TEMPERATURE - LOW

MTBF RATIO	COLDER THAN LAB	WARMER THAN LAB
≤ 1.25	64	54
> 1.25	36	46

COOLING AIR TEMPERATURE - HIGH

MTBF RATIO	WARMER THAN OR EQUAL TO LAB	COLDER THAN LAB
≤ 1.25	38	83
> 1.25	62	17

COOLING AIR TEMPERATURE RATE OF CHANGE

MTBF RATIO	LESS THAN LAB	GREATER THAN OR EQUAL TO LAB
≤ 1.25	67	32
> 1.25	33	68

COOLING AIR DURATION

MTBF RATIO	LESS THAN LAB	GREATER THAN OR EQUAL TO LAB
≤ 1.25	50	52
> 1.25	50	48

TABLE 14 DISTRIBUTION OF MTBF RATIOS FOR PRESSURE AND VIBRATION DIFFERENCES

ATMOSPHERIC PRESSURE - LOW

MTBF RATIO	- 12 to 0	< - 12
≤ 1.25	64	27
> 1.25	36	73

VIBRATION DURATION

MTBF RATIO	LESS THAN TWICE THE LAB	GREATER THAN TWICE THE LAB
≤ 1.25	67	27
> 1.25	33	73

To assure that no erroneous conclusions were drawn, the same analysis was essentially performed for just the ambient cooled boxes since these WRAs should be more sensitive to changes in ambient conditions. The results are shown in Table 12 and indicate even more strongly that temperature rate of change is the dominant factor.

Cooling Air Temperature: The analysis for cooling air temperature range, rate of change, and duration, is shown in Table 13. Field-lab MTBF correlation is better for those items whose field cooling air temperature extremes are lower than in the lab. This suggests that component life is better at lower than the lab temperatures. In addition, field cooling air temperature rates of change less than those in the lab produce better MTBF correlation, again indicating that the lab test should have more frequent and more rapid changes in the temperature environment.

Pressure and Vibration: The analysis of these environments is in its early stages. Some very preliminary results are shown in Table 14. It appears that equipments subjected to extremely lower pressure in field than in the lab have lower field MTBFs than those that were demonstrated. Similarly, more than twice the equivalent field time of exposure to vibration than the lab results in poorer field-lab correlation suggesting that the vibration test time be increased.

SECTION VI

PREDICTIONS

The predictions originally performed by each equipment manufacturer utilized a wide variety of Government sources for failure rates (MIL-HDBK-217, MIL-HDBK-217A, FARADA, etc.), as well as failure rates based on the sellers' own field experience. Further, each manufacturer also tended to apply his own ground rules when making predictions. In order to establish a common baseline for each of the selected equipments, it was decided to re-predict the reliability of each WRA using the same sources and ground rules for each. This approach then would permit consistency in comparison of predictions with reclassified lab or field MTBFs. It was further decided to use the latest procedure available, MIL-HDBK-217B Coordination Copy (ref. 11), since this represented the most current information available and would probably provide closest correlation with field failure rates.

In performing the predictions certain problems were encountered forcing specific decisions and resulting in a set of ground rules and assumptions. It should be noted that these criteria were applied to all of the selected equipments. The following major ground rules and assumptions were made:

- In several instances (capacitors and high stress ratio diodes), values for certain parameters (stress ratio vs. temp.) were of a magnitude not available from the curves. The RADC Notebook was used in these cases.
- For certain parts (e.g., mechanical items), MIL-HDBK-217, Appendix II, was used since MIL-HDBK-217B did not provide failure rates.
- Seller failure rates were utilized in those few instances where a device was considered proprietary by a seller and no information was available.
- The application factor for Group I and II transistors was assumed to be linear unless the device was used as a logic switch.
- The voltage stress for Group I Transistors was established at 60% since precise stress values were not available.

- Insert material for connectors was assumed to be Type A unless otherwise stated or known (coax).
- Voltage stress ratios for Group IV diodes was defined as 100%.
- Unless otherwise known, filter configuration were assumed to be Pi.
- An application factor of 2.0 was assigned to "CY" capacitors having a capacitance greater than 10,000PFD.
- Hybrid thin film equations were used to determine failure rates of resistor networks.

It should be noted that in most cases the re-prediction (MIL-HDBK-217B) resulted in MTBF values significantly lower than the original predictions.

The following observation and recommendations concerning MIL-HDBK-217B are offered:

- The equations prescribed for calculating hybrid failure rates are extremely cumbersome to use and, because of this, provide potential sources of error.
- The sections on passive elements (resistors and capacitors) do not include certain older types. Since many of these items are still being used, the sections should be expanded to include these parts. In addition, the first page of these sections should correlate part type and MIL SPEC.
- The original MIL-HDBK-217 included a section on basic reliability theory and math modeling, indicating how apportionments and predictions were used. MIL-HDBK-217B should also include basic theory and tutorial material to provide a complete reference source for predictions.

Table 15 presents the original prediction, MIL-HDBK-217B re-prediction and reclassified field MTBF for each of the selected equipments. In most cases, the original predicted values were higher (more optimistic) than those repredicted. In addition, the newly predicted MTBFs provided better correlation with field reliability.

Analyses will be performed during the remainder of the study to identify and quantify some of the causes of differences between predictions and field experience. This will be accomplished by relating these MTBF differences to particular design/equipment characteristics and environmental differences in a manner similar to the lab-field analysis. Quantitative expressions and adjustment factors will be developed for those relationships found significant.

TABLE 15 COMPARISON OF PREDICTED AND FIELD MTBF VALUES

WRA NUMBER	ORIGINAL MTBF PREDICTION	MTBF PREDICTION USING MIL STD 217B	FIELD MTBF	WRA NUMBER	ORIGINAL MTBF PREDICTION	MTBF PREDICTION USING MIL STD 217B	FIELD MTBF
1	495	274	246	27	3,480	744	240
2	196	290	90	28	805	778	111
3	351	175	144	29	2,884	602	143
4	469	279	127	30	3,254	1,374	780
5	483	140	584	31	2,856	556	738
6	294	171	210	32	6,684	2,345	5,903
7	1,101	730	296	33	2,361	5,625	847
8	196	290	42	34	55,556	12,837	2,045
9	3,893	1,377	1,141	35	3,013	945	646
10	294	163	139	36	16,051	4,815	1,654
11	8,547	3,076	55,996	37	2,895	443	595
12	18,519	6,901	53,868	38	3,215	607	2,444
13	823	434	331	39	2,973	557	7,333
14	3,106	5,555	954	40	3,625	671	1,466
15	37,037	19,415	17,347	41	47,619	10,906	2,045
16	50,000	115,929	12,022	42	52,632	12,846	5,903
17	966	872	194	43	50,000	13,356	4,091
18	45,454	52,596	17,347	44	395	176	33
19	9,090	899	89	45	3,610	5,841	2,753
20	805	430	72	46	650	80	42
21	4,083	6,006	3,293	47	8,000	1,483	2,337
22	4,264	1,097	738	48	2,747	314	1,042
23	3,279	1,067	409	49	1,795	1,609	636
24	390	262	268	50	481	205	138
25	3,776	399	2,389	51	3,350	2,295	313
26	2,785	1,630	2,045	52	5,025	748	292

TABLE 15 COMPARISON OF PREDICTED AND FIELD MTBF VALUES (Continued)

WRA NUMBER	ORIGINAL MTBF PREDICTION	MTBF PREDICTION USING MIL STD 217B	FIELD MTBF	WRA NUMBER	ORIGINAL MTBF PREDICTION	MTBF PREDICTION USING MIL STD 217B	FIELD MTBF
53	35,112	5,487	10,581	75	1,970	2,776	359
54	1,856	3,129	1,113	76	11,905	2,700	511
55	5,993	2,656	590	77	7,231	2,468	281
56	15,716	6,987	801	78	71,429	19,105	2,045
57	65,359	12,898	917	79	4,292	840	150
58	8,264	3,093	546	80	2,762	433	848
59	1,831	581	162	81	13,699	5,858	11,805
60	10,202	10,677	1,002	82	2,619	1,128	796
61	3,846	1,928	287	83	5,464	2,544	398
62	16,129	5,076	1,202	84	3,747	617	3,293
63	18,451	12,243	1,654	85	2,075	1,404	430
64	75,873	68,961	572	86	19,231	8,416	5,903
65	3,891	1,887	347	87	5,784	19,686	10,581
66	2,539	1,720	172	88	5,784	19,043	7,333
67	1,182	969	135	89	3,838	11,745	10,581
68	1,305	458	252	90	588,824	2,924	409
69	13,449	2,003	382	91	17,562	585,823	10,581
70	1,286	1,157	135	92	1,250,000	2,450,980	1,654
71	4,808	653	933	93	23,810	70,482	2,951
72	9,096	2,412	751	94	714,286	1,400,560	1,654
73	1,727	2,756	381	95	12,500	14,286	2,045
74	1,506	883	199				

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SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The following preliminary conclusions have been derived from the data analyzed during the study:

1. Inconsistent groundrules and failure scoring criteria account for a significant portion of the difference between lab and field MTBFs.
   a. Lab groundrules exclude too many failures.
   b. Field groundrules include too many failures.
2. There appears to be a relationship between MTBF differences and several equipment characteristics.
   a. Propulsion.
   b. Cooling requirements and cooling methods.
   c. Equipment function.
3. There appears to be a relationship between MTBF differences and several environmental differences.
   a. Temperature rate of change.
   b. Duration of temperature at extremes.
   c. Cooling air variation.
   d. Duration of exposure to vibration.
   e. Low pressure.
4. MTBF predictions using MIL-HDBK-217B are generally lower than those originally performed and tend to, in many cases, be closer to the field value.

7.2 Recommendations

Based on the above conclusions and other insights derived during the study, the following areas appear viable for further and detailed investigation:

1. Revision of vibration spectrum for equipment installed in jet aircraft
2. Increased duration of vibration exposure.
3. Modification of thermal cycle to include more temperature changes and greater rates of change.
4. Addition of some form of moisture test.
5. Different thermal tests for forced air cooled equipment compared to ambient cooled hardware.
6. New and consistent groundrules for scoring failures.
7. Equipment on/off cycling compatibility (field vs. lab) for items which are cycled often in actual use.
8. Complete functional check at least sometime during the test.

REFERENCES

1. Dantowitz, A., Hirschberger, G. & Pravidlo, D., Analysis of Aeronautical Equipment Environmental Failures, Technical Report AFFDL-TR-71-32, Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio, May 1971

2. Reliability Tests: Exponential Distribution, Military Standard MIL-STD-781

3. Electronic Equipment, Airborne, General Specification For, Specification MIL-E-5400

4. Dreher, J., Aircraft Equipment Random Vibration Test Criteria Based On Vibration Induced By Turbulent Air Flow Across Aircraft External Surfaces, Air Force Flight Dynamics Laboratory Wright-Patterson AFB, Ohio

5. Kube, F. & Hirschberger, G., An Investigation To Determine Effective Equipment Environmental Acceptance Test Methods, A. D. Report ADR 14-04-73.2, Grumman Aerospace Corp., April 1973

6. Reliability Assurance For Production Acceptance Of Avionic Equipment, General Specification For, Specification MIL-R-23094

7. Coren, G., Cotliar, W. & Conroe, D., Predicting Environmental Interaction, Fairchild-Hiller Corp., Presented at 6th Annual Reliability & Maintainability Conference, July 1967

8. Electric Power, Aircraft, Characteristics & Utilization Of, Military Standard MIL-STD-704

9. Definitions Of Effectiveness Terms For Reliability, Maintainability, Human Factors & Safety, Military Standard, MIL-STD-721

10. Failure Classification For Reliability Testing, General Requirements For, Specification, AR-34

11. Military Standardization Handbook, Reliability Prediction, Military Handbook, MIL-HDBK-217B, (Coordination Copy, July 1973).

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